USAAVLABS TECHNICAL REPORT 65-43

SURVIVABILITY SEAT DESIGN DYNAMIC TEST PROGRAM

By

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July 1965

U. S. ARMY AVIATION MATERIEL LABORATORIES

FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-191(T)

AVIATION SAFETY ENGINEERING AND RESEARCH

A DIVISION OF THE FLIGHT SAFETY FOUNDATION

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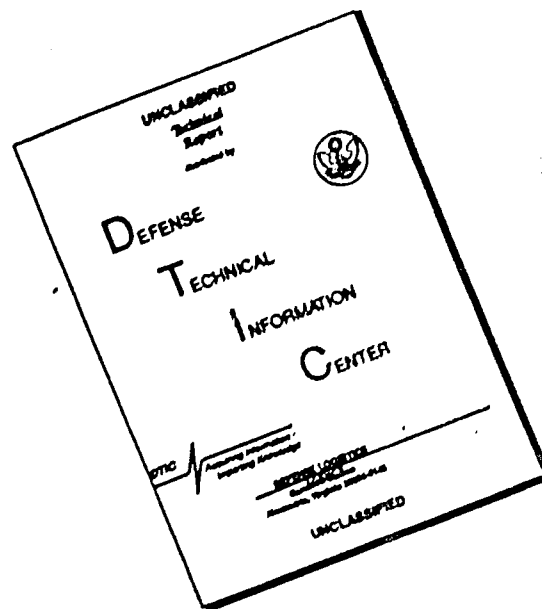
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This report has been prepared by the Aviation Safety and Research Division of the Flight Safety Foundation under the terms of contract DA 44-177-AMC-191(T); it consists of a summary of test results on the dynamic testing of four prototype aircrew crash survival seats.

The seat test data developed under this program are by no means optimum in any respect, but the information does reflect a detailed summary of a limited investigation into the feasibility cf designing aircrew seats to large dynamic load factors. The limited number of each seat available for use in these tests and the subsequent failure of some instrumentation and body retention systems contributed to a loss of important data. That information which was collected does indicate that further research is required in the areas of improving body restraint systems and seat structural requirements.

This program is but a portion of past and planned future efforts in the area of crash survival. A great deal of work remains to be done to develo. optimum crew seat designs and their related testing procedures, especially in view of the large dynamic load factors which are being considered.

Conclusions and recommendations contained herein are concurred in by this command.

SURVIVABILITY SEAT DESIGN

DYNAMIC TEST PROGRAM

by

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Prepared by

for

ABSTRACT

This report presents the results of a series of dynamic tests conducted with four different concepts of experimental crew seats.

The experimental seats were designed and constructed by four helicopter manufacturers. The seats were designed to withstand static load factors equivalent to those recommended in TRECOM Technical Report 63-4, "Crew Seat Design Criteria for Army Aircraft", dated February 1963.

The design load factors recommended in the above referenced report were as follows: longitudinal - 45G for 0.10 second; lateral - 45G for 0.10 second; and vertical - 25G for 0.10 second.

Special kits for small arms ballistics protection were also designed and installed in the seats tested.

These seats were designed exclusively using static load factors. No previous testing was conducted by any seat manufacturer prior to the conduct of these tests.

The four seats were tested under four load conditions. Two of the conditions involved simultaneous half loads on the seats in two different seat positions, and two of the conditions involved full loads in two different seat positions.

Only one of the four seats tested withstood the loads imposed for all four conditions. Three of the seats failed and were damaged beyond economical repair when each was subjected to the first full load test condition.

This report also includes a detailed description of an acceleration device which was specially designed and fabricated for this series of tests.

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INTRODUCTION

In February 1963, a report entitled "Crew Seat Design Criteria for
Army Aircraft" (TRECOM Technical Report 63-4) was published by
the U. S. Army Aviation Materiel Laboratories.* The report was
based on work conducted for the U. S. Army by the Flight Safety
Foundation, Inc. under contract DA 44-177-AMC-888(T).

The report included an analysis of strength requirements set forth in
military specifications governing the design and fabrication of non-
ejection-type crew seats currently utilized in U. S. Army aircraft.
The analysis was made in light of accident experience with existing
seats, human tolerance as presently known, and the acceleration and
force environment which may be anticipated in survivable accidents
involving U. S. Army aircraft.

The analysis revealed that the strength requirements, as set forth in
current military specifications, are too low. Human tolerance limits
and data measured in experimental crash tests exceed the current seat
strength levels. The analysis substantiated the observation by the
U. S. Army that seats currently in use failed under relatively moderate
accident conditions, thus subjecting the occupants to further hazards,
especially in increased contact injuries.

Based upon this study, it was recommended that current seat specifi-
cations be revised as follows:

1. Longitudinal and Lateral Design Loads: The seat, its support
   system and the occupant restraint system should, individually
   and in combination, be capable of maintaining 25G for 0.20
   second and 45G for 0.10 second in the pelvic region of a suitable
   anthropomorphic dummy having a weight and mass distribution
   of that of the heaviest occupant expected. Progressive plastic
   deformation of the seat and restraint system is permissible
   provided (1) complete failure and (2) subsequent injurious
   situations do not occur.

2. Vertical (Headward) Design Loads: The seat, its support
   system, and the occupant restraint system should, in combi-
   nation, be capable of continuously maintaining 25G ± 5G, in the
   pelvic region of the dummy described in (1) above, while de-
   forming through at least 12 inches of vertical travel with respect
   to the airframe and, where possible, up to 15 inches or more of
   vertical travel.

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* Formerly U. S. Army Transportation Research Command.

Immediately after publication of the aforementioned report, the U. S. Army Aviation Materiel Laboratories awarded contracts to four helicopter manufacturers (Bell Helicopter Company; Vertol Division, The Boeing Company; Sikorsky Aircraft Division, United Aircraft Corporation; and Kaman Aircraft Corporation) for the design and fabrication of experimental crew seats built to the load factors recommended in the above referenced report and also incorporating a small arms ballistics protection capability. These seats were developed for use as test beds to determine their crashworthiness and ballistic protection effectiveness. Each manufacturer was permitted to utilize his own ingenuity in designing and fabricating the experimental seats resulting in four different concepts for meeting the load factor requirements. Each manufacturer fabricated two seats.

In June 1964, the Flight Safety Foundation, Inc. was awarded contract DA 44-177-AMC-191(T) to conduct a dynamic test program on the four experimental seats. Simulated crash conditions were to be used, in order to evaluate the structural integrity and energy absorption capabilities of each seat. This report presents the test methods and procedures followed and the results obtained during the conduct of this test program.

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CONCLUSIONS

On the basis of the information obtained during the series of tests, it is concluded that:

1. Current military specification restraint systems, such as those used in three of the seat systems tested, are inadequate for the loads imposed on the seats.

2. The failure of the restraint systems in three of the seats contributed to a redistribution of load which caused seat failures at loads below the design specifications.

3. The excessive stretch which occurred with the above referenced restraint systems, combined with soft cushions utilized in some of the seats, resulted in dynamic overshoot which exceeded published human tolerance values in some of the tests conducted.

4. Several energy absorption systems failed to function, either because of failure of the restraint system (thereby not loading the seat) or because of the presence of non-ideal loading conditions.

RECOMMENDATIONS

On the basis of the foregoing conclusions, it is recommended that:

1. Improved restraint harnesses be developed which will remain intact up to the design strength of the seats to which they are attached and that they be constructed of materials which allow a minimum of stretch under dynamic loading conditions.

2. Consideration be given to the use of cushions which will prevent dynamic overshoot, as experienced in several of the tests conducted, because of the softness of the cushions used.

3. A research program be initiated for the purpose of establishing improved design criteria for restraint systems and cushions for use in the design and development of future military crew seats.

4. Additional research be conducted to define human tolerance levels better under conditions of impact acceleration involving several components simultaneously.

5. Future seat design efforts include limited dynamic testing prior to full-scale testing; and that a minimum of five seats be furnished for any full-scale dynamic test program.

DISCUSSION

GENERAL

The loads imposed on these seats were quite severe even in the "half-load" shots and probably exceeded human tolerance values, as set forth in TRECOM Technical Report 63-4, particularly in the "full-load" shots. This was due to the dynamic overshoot which is obvious in the recorded data.

Dynamic overshoot will always be present between the seat and dummy occupant because of the impracticality of restraining the dummy with zero slack in the system. Present systems can be improved by the use of optimum cushioning and by the use of restraint harnesses employing low-stretch materials.

Some starting point was necessary for the test series, and input loads equal to the full human tolerance and one-half of the tolerance were chosen with the full realization that these tolerance levels might be exceeded in the full-load series.

BELL SEAT

The results of the half-load tests show that the Bell seat is probably well designed structurally to withstand the accelerations appropriate to the half-load test. The primary problem area apparent was the high degree of longitudinal dynamic overshoot resulting from elasticity of the restraint system. The forces transferred to the dummy in the half-load tests approached (and in some cases exceeded) the human tolerance levels. Failure of the restraint harness was thus anticipated in the full-load tests.

The full-load (45G) test exceeded the structural capacity of the seat. The acceleration base pulse (input to the sled), was considerably below the specification originally set for the seat. The loads which induced failure were probably the result of dynamic overshoot. Dynamic overshoot cannot be entirely eliminated in a seat restraint system; however, it can be reduced to reasonable limits by proper selection of harness and cushion materials.

The design concept of the jettisonable chest armor used by the Bell seat was valid; that is, it allowed the armor to fail rapidly from longitudinal

loads. This system removes the armor from the seat and thus does not load the seat. However, there are problems resulting from this principle. First, the presence of high vertical loads may cause the armor to impact the occupant's legs prior to leaving the seat envelope. Second, the failures in the armor occur where the armor plate itself connects to the aluminum rods designed to keep the armor above the occupant's legs. Thus, two jagged projections are left, which, in the half-load test with a vertical component, contacted the right leg of the dummy. An injury could have resulted from this. Third, the armor will become a loose "missile". The armor would probably fly clear of the seat; however, it might be possible for the armor to strike the console or other structural member and rebound into the occupant.

KAMAN SEAT

The Kaman seat appeared to carry the loads imposed in the half-load tests adequately. No satisfactory conclusion can be drawn concerning the ability of the seat to carry the full-load when properly restrained at the floor mounting.

One problem that became apparent during the test series was the difficulty in ascertaining when the seat is properly fastened to the seat track. There is no visual or otherwise possible way of inspecting the seat pins in the track. The only evidence is the position of the pin retract handle, which unfortunately has sufficient spring to indicate a fully locked position when such is not the case. This problem was particularly important in the full-load longitudinal and vertical test where the entire seat and dummy came loose from the tracks. Post test examination showed the pins to be inserted only 1/8 inch, although all methods available were used to check on the complete seating of the pins.

The same problem of dynamic overshoot was present in this seat. The combination of a soft seat cushion and slack in the restraint harness caused acceleration loads on the dummy occupant well in excess of the input acceleration.

SIKORSKY SEAT

No failures of the Sikorsky seat or restraint harness occurred in the tests described. A failure occurred in one test due to the failure of

th(load link attachment. This attachment was not a part of the seat, and in subsequent higher loadings, the failure was not repeated. The excellent agreement between "sled" and "seat" accelerations indicates that the seat and its attachments are rigid. The seat and restraint systems are adequate for the decelerations imposed in all tests. The dummy occupant experienced some dynamic overshoot, and the energy absorber failed to function at the intended design load of 20G.

VERTOL SEAT

The failure of the restraint system in the Vertol tests did not allow a satisfactory evaluation of the seat proper. It was noted, however, that with the initial crushing of the vertical energy-absorbing "louvers" in test No. 1, the seat rigidity in the lateral direction was appreciably reduced. The seat could be readily moved from side to side by hand. Because failure of the restraint system was so pronounced in this seat, the energy absorbers and the seat-to-wall inertia reel that were intended to prevent tipping of the seat could not be effective. No conclusions can be drawn as to whether the energy absorbers and the tip-over mechanism would have functioned had the restraint system remained intact.

DESCRIPTION OF TEST ITEMS

BELL EXPERIMENTAL CREW SEAT

The Bell seat design was adapted from the current UH-1B configuration (see Figures 1 and 2). This design consists of a tubular seat frame which supports a seat bucket formed from lightweight aluminum sheet. Four aluminum slide fittings which are attached to the back and sides of the bucket provide restraint of the bucket to the frame. These fittings are interconnected horizontally by steel tubes and slide on the aft member of the seat frame. The seat is attached to the airframe through two tracks connected between the fore and aft vertical members of the seat frame. Fore and aft adjustment of the seat is accomplished by positioning spring-loaded pins into holes in the seat floor track. Vertical adjustment was not provided in this experimental design.

Ballistic protection is provided by armor material mounted across the back, bottom, and front lip of the seat bucket. A chest protector is mounted from the front of the seat bucket by two aluminum supports. Lateral ballistic protection is not integral to the seat envelope but is designed to be installed on the crew doors of the UH-1 helicopter.

Occupant restraint is provided by a seat belt, shoulder harness, and crotch strap connected at one central fitting. Operation of this fitting releases all harnesses simultaneously. Vertical crash forces are attenuated by a series of cable-sheave-type energy attenuators which are mounted between the steel tube which connects the seat bucket slide fittings and a horizontal member of the seat frame. These devices function by progressively failing the lips of the sheave which are pressed over a steel cable circling the periphery of the sheave.
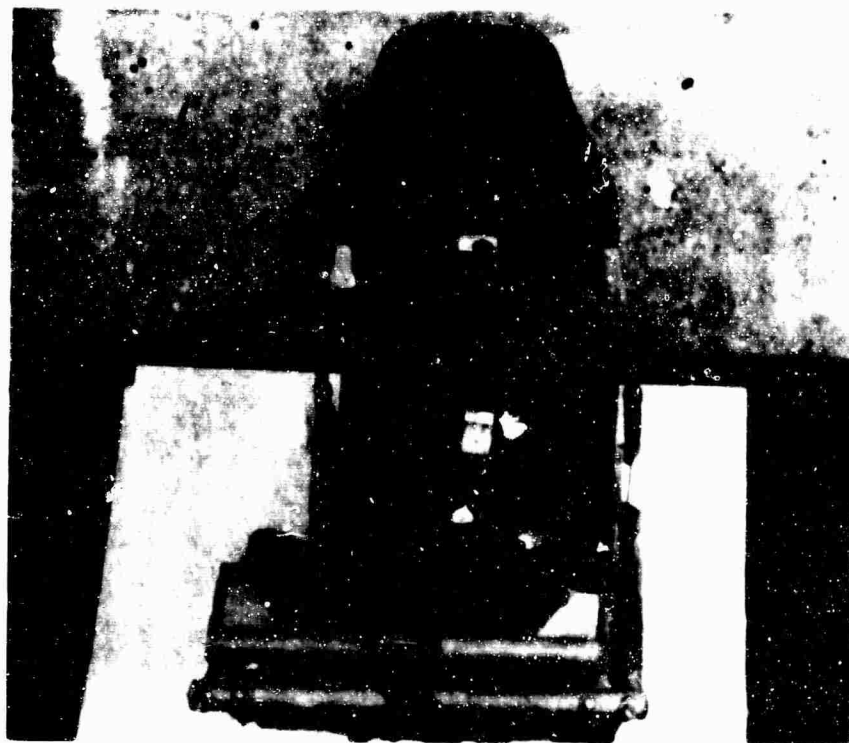
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Figure 1. Side View of Bell Seat.

Figure 2. Top View of Bell Seat

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KAMAN EXPERIMENTAL CREW SEAT

The Kaman seat design consists of a built-up sheet metal frame which
supports a sheet aluminum seat bucket (see Figures 3 and 4). Roller
fittings are provided on the inside of each side of the support frame
and at the center of the back of the support frame for restraint of the
bucket to the frame. The seat is attached to the airframe through
tracks mounted at each end of the side support members. Fore and
aft adjustment is provided by positioning spring-loaded pins into holes
in the seat floor track. Vertical adjustment is provided by shear
lugs on the bucket which latch into a notched guide on the seat support.

Ballistic protection is provided by armor material mounted on the side,
bottom, and back of the seat bucket. The bottom and back armor
material is used as structural elements of the seat bucket. In addition,
a shoulder panel is cantilevered from the upper right corner of the
seat bucket and a torso shield is provided which completely envelopes
the upper chest area. Both the shoulder panel and the torso shield are
hinged to allow easy egress. The torso shield is attached to the seat
bucket through a support linkage and a nylon strap which encircles the
shield and bolts to the support linkage.

Occupant restraint is provided by a seat belt, shoulder harness, and
crotch strap connected at the seat belt release buckle. Release of
the seat belt simultaneously releases the shoulder harness and crotch
strap. Vertical crash force attenuation is provided by a metal bend-
ing device installed parallel to the seat back connecting the seat bucket
to the support frame. This device functions by bending and rebending
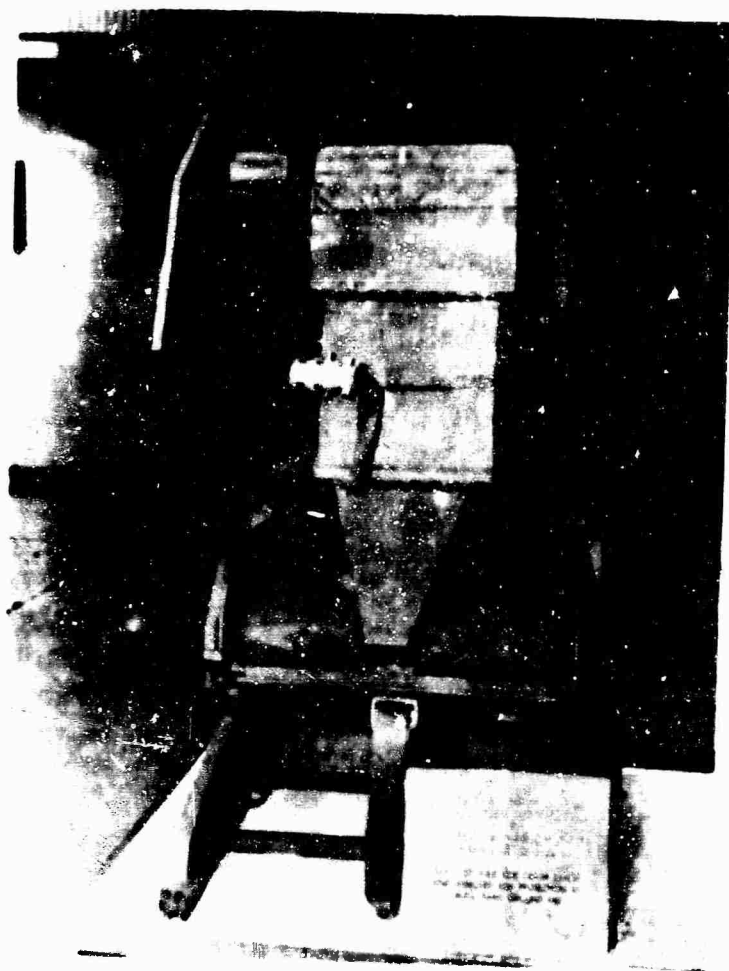four metal straps around a set of pins.

Figure 3. Front View of Kaman Seat.

Figure 4. Top View of Kaman Seat.

SIKORSKY EXPERIMENTAL CREW SEAT

The Sikorsky seat design consists of two vertical track members connected by an aluminum seat pan at the bottom (see Figures 5 and 6). The upper connecting member and seat back are constructed of the armor material. The seat is attached to the airframe through the vertical track members. Vertical adjustment is provided by positioning a spring-loaded pin in holes in the aircraft mounting track. Fore and aft adjustment of the seat is not provided in this experimental design.

Ballistic protection is provided by the armor panels used as structural members in the sides and back of the seat and by panels mounted on the bottom and front lip of the seat pan. A chest protector is provided which is mounted in slots on each of the side armor panels. The chest protector is hinged at the top to allow motion of the pilot during flight operations.

Occupant restraint is provided by a seat belt, shoulder harness, and crotch strap connected at one point on the seat belt release buckle. Operation of the seat belt release buckle allows release of the shoulder harness and crotch strap. Vertical crash forces are attenuated by crushing an aluminum honeycomb material inserted in the seat support tracks.

Figure 5. Front View of Sikorsky Seat.

Figure 6. Top View of Sikorsky Seat.

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VERTOL EXPERIMENTAL CREW SEAT

The Vertol seat design consists of a seat bucket formed of the armor material supported vertically by a series of metal honeycomb blocks and longitudinally by a screw jack at the bottom and a nylon strap attached to the airframe structure at the top (see Figures 7 and 8). The seat is attached to a floor plate through the honeycomb blocks. The floor plate is then fastened to the aircraft floor structure. Vertical and longitudinal seat adjustment is accomplished by moving the screw jack. As the screw jack moves the seat fore and aft, the seat support honeycomb blocks pivot around one edge providing vertical seat adjustment simultaneously.

Ballistic protection is provided by the armor used in the seat bucket. In addition, a chest protector and shoulder shield are provided. The shoulder shield is hinged at the top right corner of the seat bucket. The chest protector is supported vertically by a single fitting which connects at the center front lip of the seat pan. The pilot shoulder harness is used for longitudinal restraint of the chest protector.

Occupant restraint is provided by a seat belt and shoulder harness. As the chest protector is in 'ed inside the shoulder harness, it also contributes to a degree in the longitudinal restraint. Vertical crash forces are attenuated by crushing the honeycomb support blocks and a block of honeycomb which is attached between these blocks and the bottom of the molded armor seat bucket.
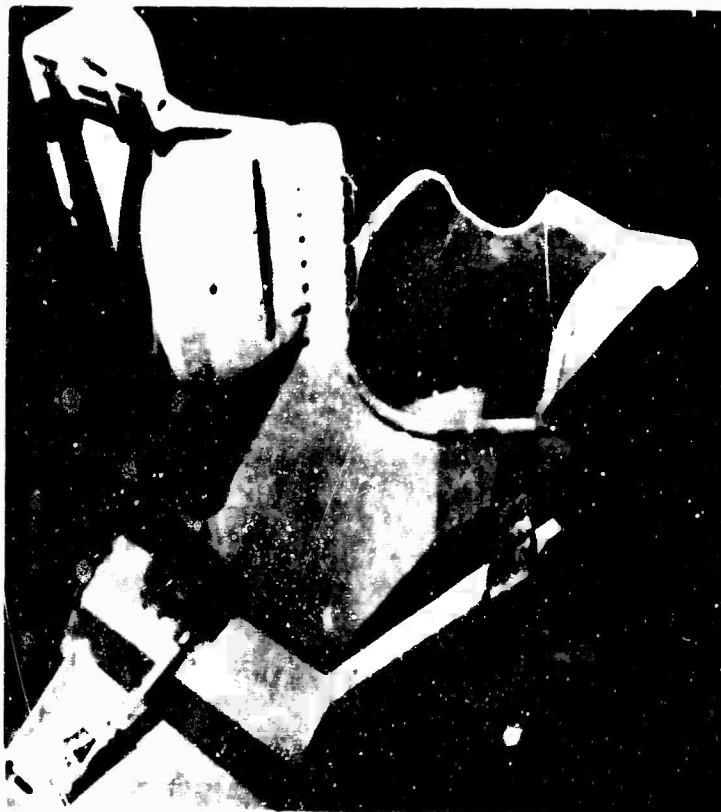
Figure 7. Side View of Vertol Seat.

Figure 8. Rear View of Vertol Seat.

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TEST PROCEDURES AND CONDITIONS

GENERAL

The procedures followed in the conduct of this test program consisted of four major steps, as follows:

1. The design, fabrication, and calibration of a mechanical device capable of developing the required input acceleration-time pulse.

2. The adaptation of available instrumentation data recording equipment for obtaining data during each test.

3. The testing of one experimental crew seat of each type to a half-load test under two specified loading conditions.

4. The testing of a second experimental crew seat of each type to a full load test under two specified loading conditions.

TEST CONDITIONS

It was planned that each of the four experimental seat designs would be subjected to the following test conditions.

TEST CONDITIONS

Test Condition	Deceleration Levels (G)	Time Duration
(1) Simultaneous Vertical and Longitudinal Deceleration	Vertical G_V -12.5 Longitudinal G_L -22.5	0.1 Sec.
(2) Simultaneous Lateral and Longitudinal Deceleration	Lateral G_{La} -22.5 Longitudinal G_L - 22.5	0.1 Sec.
(3) Simultaneous Vertical and Longitudinal Deceleration	Vertical G_V -25 Longitudinal G_L - +5	0.1
*(4) Simultaneous Lateral and Longitudinal Deceleration	Lateral G_{La} - 45 Longitudinal G_L - 45	0.1 Sec.

* The Bell, Kaman, and Vertol Seats were not subjected to this test condition as they were damaged beyond economical repair during Test (3).

DESCRIPTION OF TEST DEVICE

General

The test device used in this program consisted of a mechanical thruster designed to give a predetermined acceleration pulse to a rigid sled. The basic construction of the thruster is shown in Figure 9. The test area consisted of the mechanical thruster which propelled a rigid sled down a concrete supported track. The test specimens were mounted upon the sled, instrumented electronically, and optically recorded by 16mm-film cameras. (Reference Figures 10 and 11) The accelerating force is generated by steam and gas pressure on the piston.
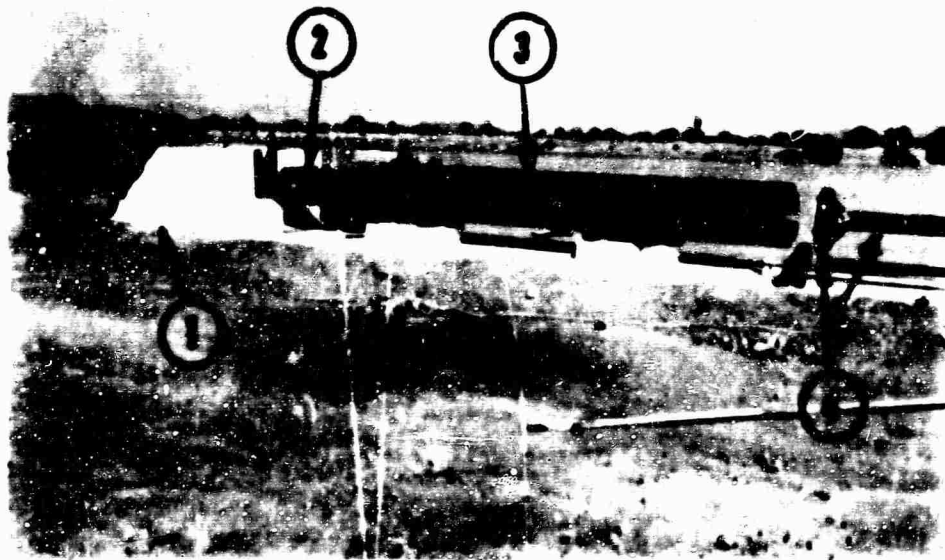
Figure 9. Mechanical Thruster Device.
(Legend: (1) thruster base,
(2) fixed piston, (3) main
tube, and (4) free piston)

The major components of the test apparatus are indicated by the arrows in Figure 9. The thruster base, as indicated by arrow 1, is a reinforced concrete structure capable of withstanding all loads (up to 180,000 pounds)
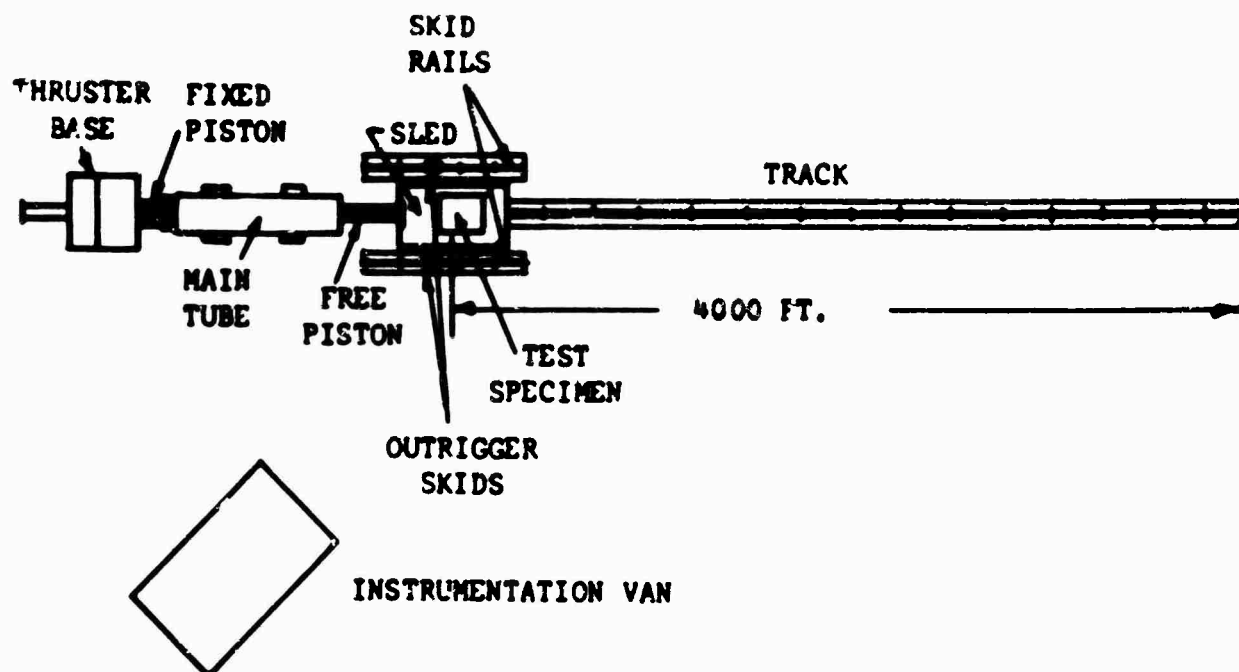
Figure 10. Test Area.
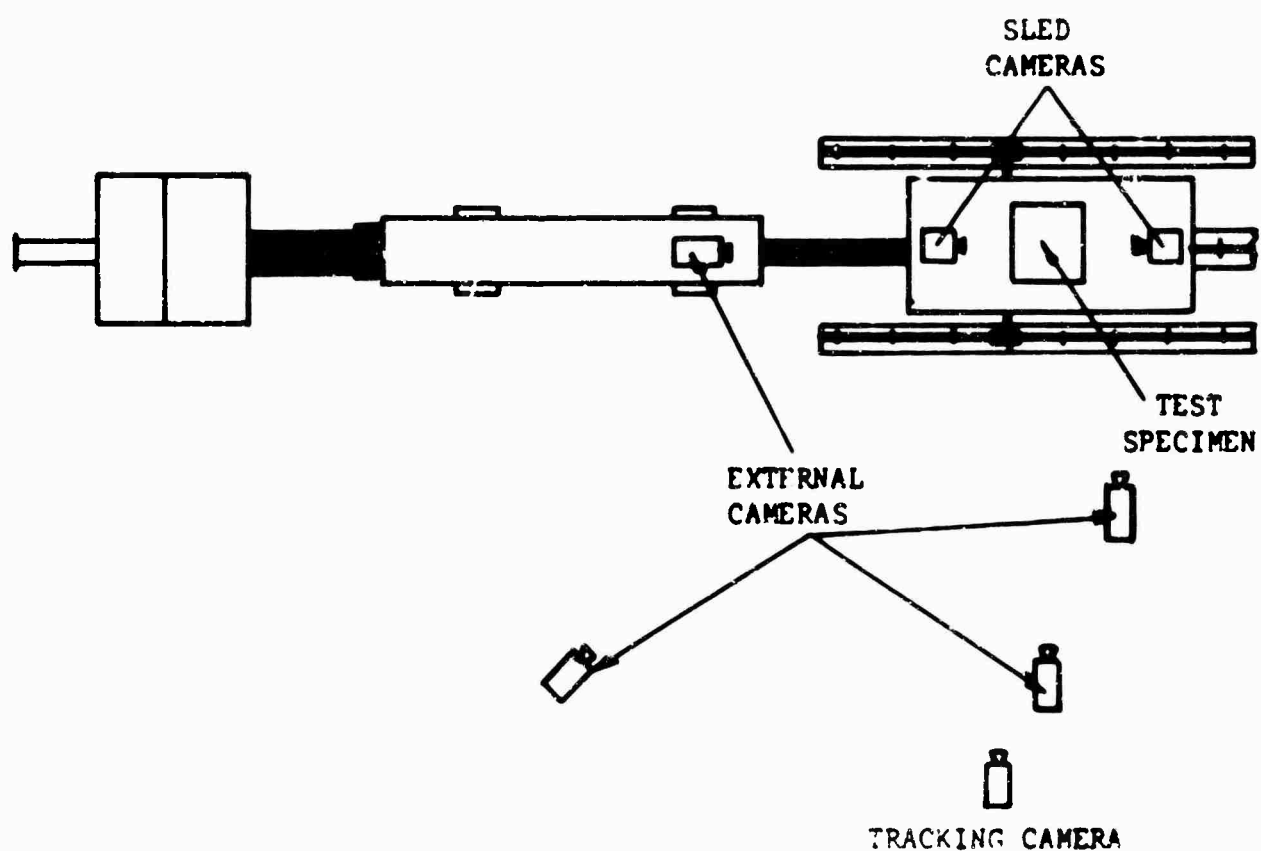
Figure 11. Camera Coverage of Test Specimens.

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generated by the thrust device. The fixed piston indicated by arrow 2
contains the steam generating apparatus and can be moved into the main
tube to allow variation in stroke lengths. The main tube indicated by
arrow 3 is similar to a gun barrel allowing one direction movement of
the free piston shown by arrow 4. The free-piston drive rod is of such
length as to provide for the variation in stroke lengths required by
different tests. The free piston and drive rod are connected to the sled
on which the test specimen is mounted at the point indicated by arrow 1
in Figure 13. The sled moves along a three-rail track system (arrow
2 in Figure 13), during the acceleration stroke and then rides out along
a monorail with outrigger skid support during the slow deceleration to
rest.

Steam Generator Assembly

The method of steam generation is shown schematically in Figure 12.
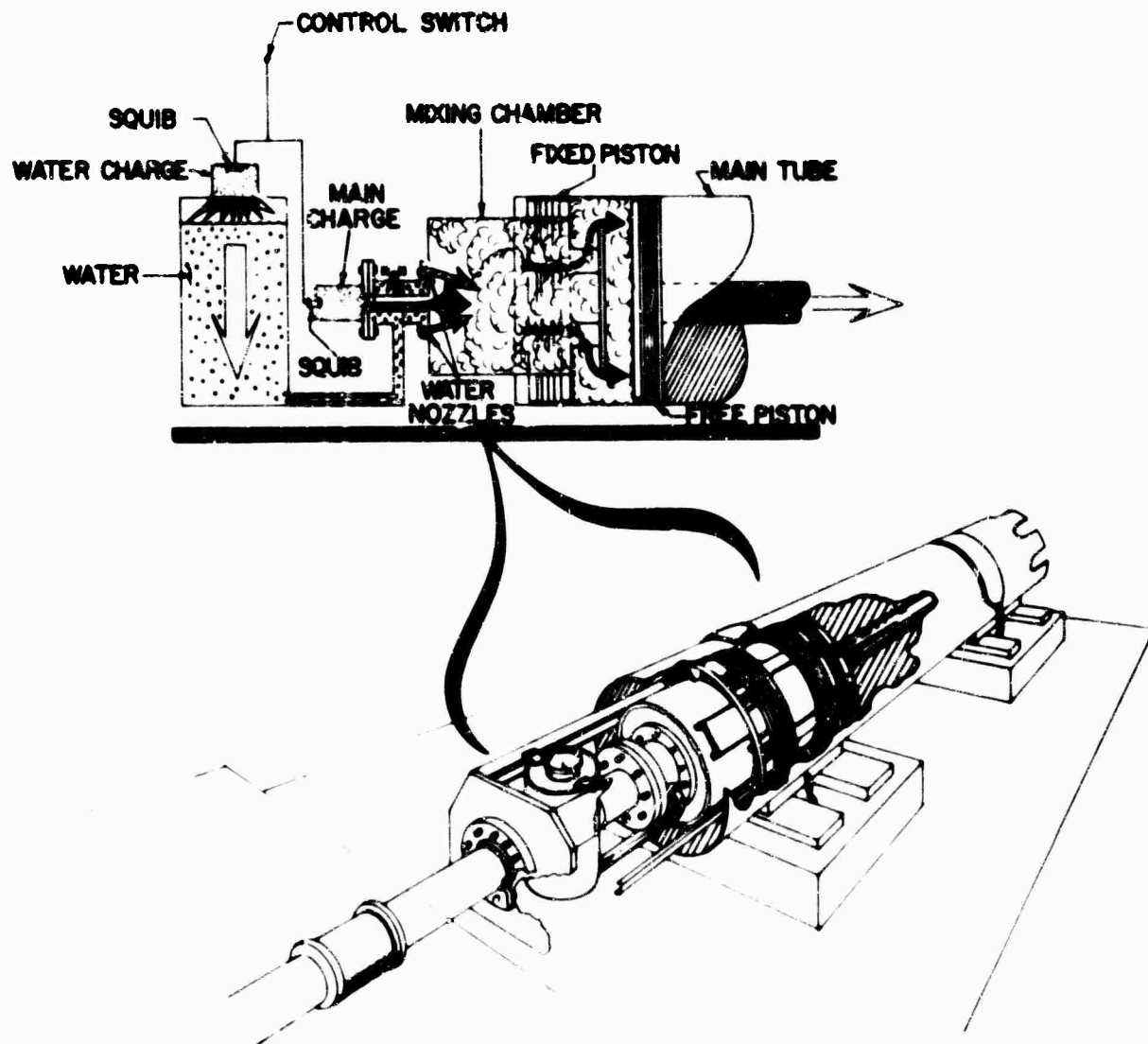
Figure 12. Schematic Drawing of Steam Generation System.

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The principles of the steam generation system are quite simple; that is, a solid propellant charge burning at 5000 degrees F turns water into steam instantaneously. However, to have a predictable and repeatable experiment, several refinements were required in the system.

Immediately prior to firing, the chamber A of the device is filled with water. The water is prevented from entering the mixing chamber by closed core plastic plugs. The tube through chamber A is a graphite lined steel tube through which the burning of the solid propellant is directed.

To start the firing sequence, the squib on the water tank charge is fired; then, in turn, the solid propellant charge which pressurizes the water is ignited. The pressure of the water blows the plastic plugs and forces the water through the nozzles. The nozzles are designed to direct the stream of water to the center axis of the mixing chamber.

Ten milliseconds after the water charge is fired, the squib on the main charge is fired; then, the main charge solid propellant is ignited. The shaped charge, characteristic of the solid propellant, forces the combustion action down the center of the mixing chamber. As the pressurized water contacts the 5000 degrees F burning propellant, steam is generated so rapidly that the pressures desired for pushing the free piston at the desired acceleration are achieved instantaneously.

The movement of the free piston creates an increasingly larger volume to be filled with steam. To maintain the proper pressure for generation of a trapezoidal pulse shape, the burning rate of the propellant is increased as the volume of steam required is increased.

The variables which control the amount and the rate of steam generation are the size and burning rate of the charge and the number of water nozzles directed into the mixing chamber. For the half-load charge, six of the nine water nozzles are blocked with semipermanent plugs to allow less water into the mixing chamber. For the full-load charge, all nine nozzles are used to deliver water. The solid propellant charge varies from a 6-inch-diameter cylinder, 5 inches long for the low charge to the same size cylinder 9 inches long for the full charge.

Test Sled and Seat Mounting Jigs

The test sled was designed to the following requirements:

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1. To withstand forces of 100,000 pounds without distortion.
2. To carry the load of a 75-pound piston extended 14 feet from the body of the sled.
3. To be free of extraneous vibrations or inputs during the power stroke.
4. To run out after the power stroke on a single track.
5. To provide room for rigid mounting of the test seats plus necessary instrumentation.
6. To have the maximum weight of the completed sled be 1,500 pounds.

A photograph of the completed sled is shown in Figure 13. The sled was constructed of a mild steel I-beam centrally located and surrounded by a frame of steel channel. The piston extension was designed from a 6-inch diameter, 3/8-inch wall steel tube, which was attached to an aluminum piston. The sled was designed to ride a center rail on steel shoes with a brass running surface. Special outrigger shoes ride on rails to either side of the center rail during the power stroke and thereafter slide along the ground.

Figure 13. Typical Seat Installation on Test Sled.
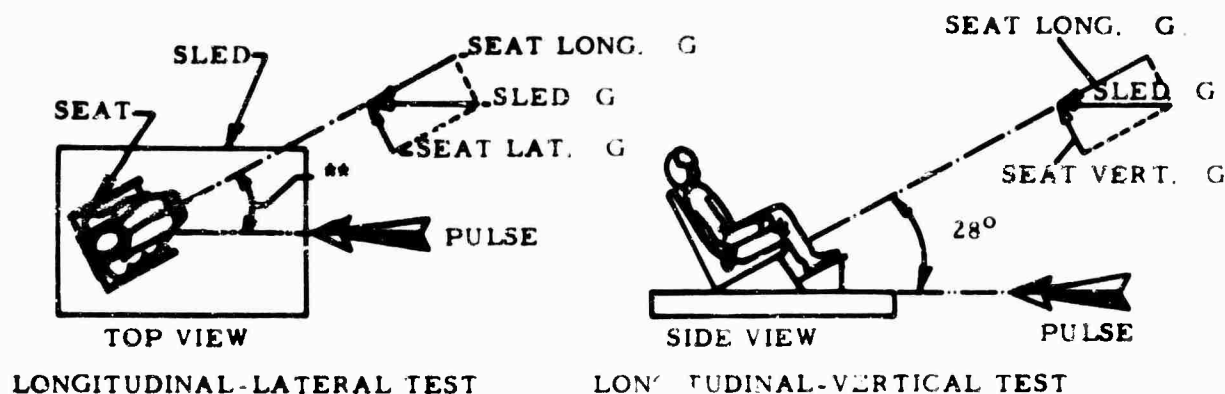
Figure 14. Seat Orientation Diagram

The weight of the sled was 1,500 pounds divided into 390 pounds for the piston and extension tube, 100 pounds for the riding shoes, and 1,010 pounds for the main body of the sled.

The large variation in the mounting systems required for the various seats necessitated a reasonably complicated mounting system in order to accommodate the seats. In addition, the variation in design specification of 10.5G maximum lateral acceleration for the Kaman seat further complicated the mounting system.

Lateral Mounts

The Bell and Kaman seats were mounted on floor tracks. A rigid floor was simulated by using steel channel. The tracks were then bolted to the channel and the seats were mounted on the tracks.

The Vertol seat was bolted directly to the floor. To simulate a rigid floor, the seat was bolted to a steel plate which was, in turn, bolted to the sled. The Vertol seat also had a connection to a bulkhead behind the seat which contained a slide device. This bulkhead was simulated by a tripod supporting the slide device at the proper height.

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The Sikorsky seat was designed with vertical tracks; therefore, was mounted to a simulated bulkhead constructed of steel channel.

The original contract called for: (1) combined lateral and vertical loads and (2) combined longitudinal and vertical loads. Since the conduct of these tests would obviously expend the energy-absorbing qualities of the seats before the final completion of the test series, condition 1 was altered to combined lateral and longitudinal loading. Unfortunately, the "G" level requirements for the combined lateral and vertical loading was carried on to the specifications for the lateral and longitudinal tests, that is, a 22.5G longitudinal and 12.5G lateral loading, which would be a full half load if vertical were substituted for lateral. This was discovered subsequent to the Vertol test and corrected. The Bell and Vertol tests were not repeated since they were half-load tests and presumably would be picked up at the full-load value.

Vertical Mounts

The vertical mounts were similar to the lateral mounts but had the added requirement of tilting the simulated floor upward 28 degrees to give the proper proportion of longitudinal and vertical accelerations.

The requirement that the mounts be rigid to isolate the test of the seat required the use of high-strength mounts. Weight was considered but, nevertheless, most of the mounts weighed nearly 200 pounds.

The weight of the basic instrumentation, that is, cables, transducers an pickup points, is included in the sled weight. The addition of on-board cameras and batteries increased the basic weight approximately 100 pounds.

For the test and calibration series prior to the actual seat shots, a weight of 2,075 pounds was used as follows.

Sled	1,500 pounds
Mount	200 pounds
Seat	175 pounds
Dummy	200 pounds
Total	2,075 pounds

This compares with actual weights for the vertical component shots shown as follows:

Seat	Weight (pounds)
Bell	1,9^?
Vertol	2,1..
Kaman	2,034
Sikorsky	2,070

The weights in the lateral shots were approximately the same plus or minus 25 pounds.

The 2,075 pound weight was chosen as representative of the group of seats. A shot with correct component values with this weight will give results for the other seats within tolerances. For example, using a nominal steam pressure of 120 psi and the piston area of 434 square inches, a force of 52,080 pounds is exerted on the sled. With the efficiency of the system approximately 95 percent, the "G" levels on the seats would vary about 2G or within the tolerance provided.

INSTRUMENTATION

Electronic Data Transducers

Transducers were installed during the test runs to record the following measurements:

1. Test sled velocity
2. Test sled acceleration - longitudinal
3. Seat acceleration - lateral
4. Seat acceleration - longitudinal
5. Seat acceleration - vertical
6. Anthropomorphic dummy pelvic acceleration - lateral
7. Anthropomorphic dummy pelvic acceleration - longitudinal
8. Anthropomorphic dummy pelvic acceleration - vertical
9. Seat belt force
10. Shoulder harness force
11. Seat floor attachment force (Bell seat only, as mechanical design of other seats did not permit incorporation of this measurement.)

The accelerometers used in this test series were a strain-gage-type Statham, Models A5A and A6A. The force tensiometers used were special fittings to which strain gages had been installed. Calibrations were made on the completed assembly prior to the test run. The seat/floor attachment force was measured by installation of foil-type strain gages on the lower tube fittings of the seat frame. (See Appendix.)

Electronic Data Recording System

The output of the data transducers was recorded on a magnetic tape recording system designed for previous dynamic crash test programs. The major components of the recording system, the signal conditioning equipment, the subcarrier oscillator, the mixer amplifier, the magnetic tape recorder, and the associated power supplies were mounted at a fixed location at the test site. Shielded cables connected the transducers to the recording system package through a disconnect mounted at the front of the sled. Since data were required only during the first few feet of travel, it was not necessary to mount the recording equipment on the test device. The shielded cable was long enough to provide all necessary data prior to disconnect. The magnetic tape recording system utilizes a constant bandwidth FM/FM multiplex modulation technique in which the analog signal from the transducer is converted by the subcarrier oscillator into a frequency deviation proportional to the input signal amplitude. Seven of these subcarrier oscillator outputs are combined in a mixer amplifier, and the resulting composite signal is recorded on 1 track of a 14-track tape recorder.

Electronic Data Processing System

The data recorded on the magnetic tape recording system were recovered by utilizing the USAAML[*]/AvSER data processing system designed and fabricated under previous crash test programs. The playback tape recorder removed the composite signal from each track and processed it through a series of FM discriminators which separated the composite signal into various subcarrier frequency deviations. These frequency deviations were then converted to an analog signal which was recorded directly on an oscillograph plotter. The resulting oscillograph record was processed and was available as a scaled analog plot of the recorded parameter.

Photo Instrumentation

Photosonics Model 1B 16mm high-speed cameras operating at 500 frames per second were used to record the dynamic response of the

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*Changed to USAAVLABS after report prepared.

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seat and dummy during each test run. Three of these cameras were
used during the half-load test conditions (1) and (2). One camera was
mounted over the main thruster tube providing a front view of the
dummy and seat. Another was mounted at an angle of 90 degrees to
the test sled, providing a side view of the power stroke. The last was
mounted at an angle of 45 degrees to the right front of the sled to pro-
vide overall coverage of the entire test sequence. During the full-load
test series, additional high-speed cameras were mounted on the test
sled to provide detail coverage of specific areas of interest.

A Bolex Model H-16 normal speed camera operating at 24 frames per
second was used to provide documentary coverage of each test.

CAMERA LOCATIONS

| Test Seat | Test Condition | High-Speed Camera | | | | | | Bolex |
		1	2	3	4	5	6	7
Bell	2	x	x	x				x
Vertol	2	x	x	x				x
Kaman	2	x	x	x				x
Bell	1	x	x	x				x
Kaman	1	x	x	x				x
Vertol	1	x	x	x				x
Sikorsky	1	x	x	x				x
Sikorsky	2	x	x	x				x
Sikorsky	3	x	x		x		x	x
Bell	3	x	x		x	x	x	x
Kaman	3	x	x	x	x	x		x
Vertol	3	x	x	x	x	x		x
Sikorsky	4	x	x	x	x	x		x

* OVERHEAD CAMERA 2 - 4'
ABOVE DUMMY

(7) DISTANCE AS REQUIRED FOR TRACKING
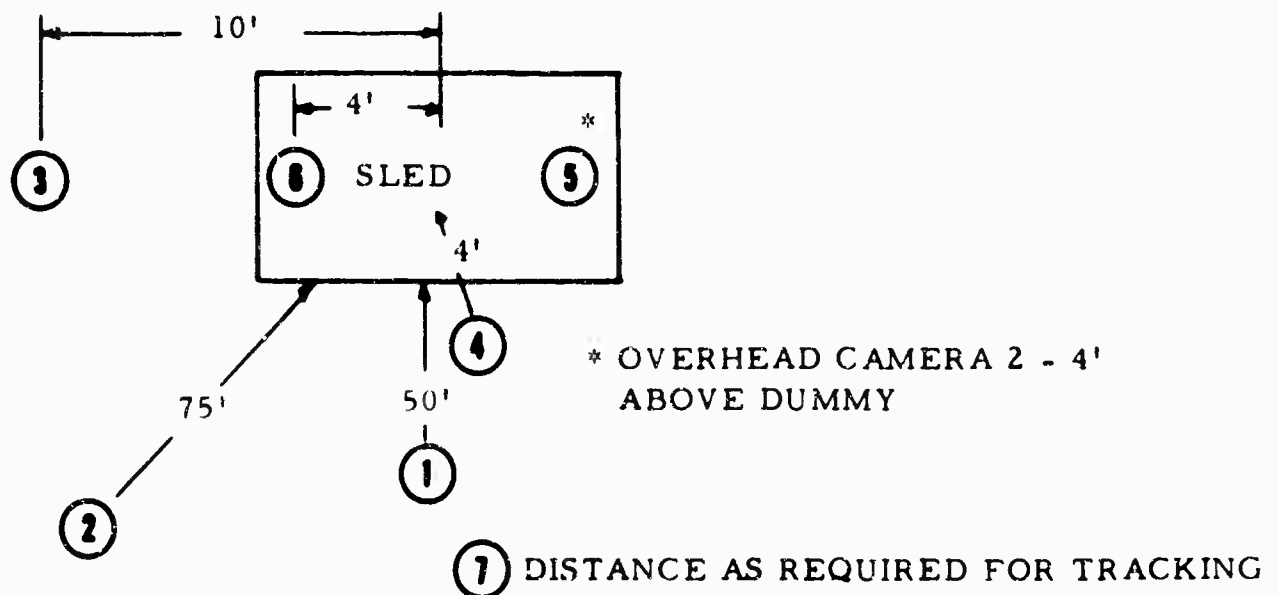
TEST RESULTS

GENERAL

This section of the report contains the results of the tests conducted on the four experimental seats described in the previous section. Orientation of the seats for the various test conditions is illustrated in Figure 14. During the conduct of all tests, inertia reels were manually locked prior to all tests in order to tighten shoulder harnesses and seat belts as tautly as possible. The following is a description of the tests and data obtained for each seat and test condition.

BELL SEAT TEST CONDITION NO. 1

Under this test condition, the seat was oriented 28 degrees from he horizontal, as shown in Figure 14, to give both longitudinal and vertical loading of the seat. As the seat accelerated, the dummy moved downward into the cushion and, at approximately 0.01 second, it began to move forward with respect to the seat. The chest armor plate was also moving forward at this time. At approximately 0.03 second, the chest armor plate had moved forward through its maximum permissible travel distance, failed as designed, and jettisoned clear of the sled. It was also at this point that the dummy began to accelerate with the sled. The sled had traveled approximately 18 inches before the dummy began to accelerate. Figure 15 is a posttest view of the seat and dummy, showing the forward bulge on the front seat pan lip (arrow) caused by the dummy's moving downward and forward during the initial phase of the acceleration. The figure also shows the failure of the chest armor plate support tube. During some part of the test, the left seat belt became disconnected at the latch; however, the remaining restraint harness was sufficient to retain the dummy in the seat. The energy absorbers gave only a slight indication of operating. They should not have operated, of course, to any extent, since the vertical acceleration did not exceed their design load (20G), for any appreciable time.

The sled acceleration-time plot is given in Figure 17G. The peak pulse was 23G. The 23G sled pulse, when divided into "seat" components (in accordance with Figure 14), gives 20G longitudinal and 11G vertical. The seat accelerometers gave peak readings of 20G longitudinal and 12G vertical, showing good agreement (Figures 17B and 17C). Figure 17A, typical of all of the tests conducted, shows no lateral acceleration in this longitudinal-vertical test. The dummy (see Figure 17D) showed a very small lateral response, which is attributed to a slight misalignment of the dummy on other components.

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Figure 15. Posttest View of Bell Seat - Test Condition No. 1.

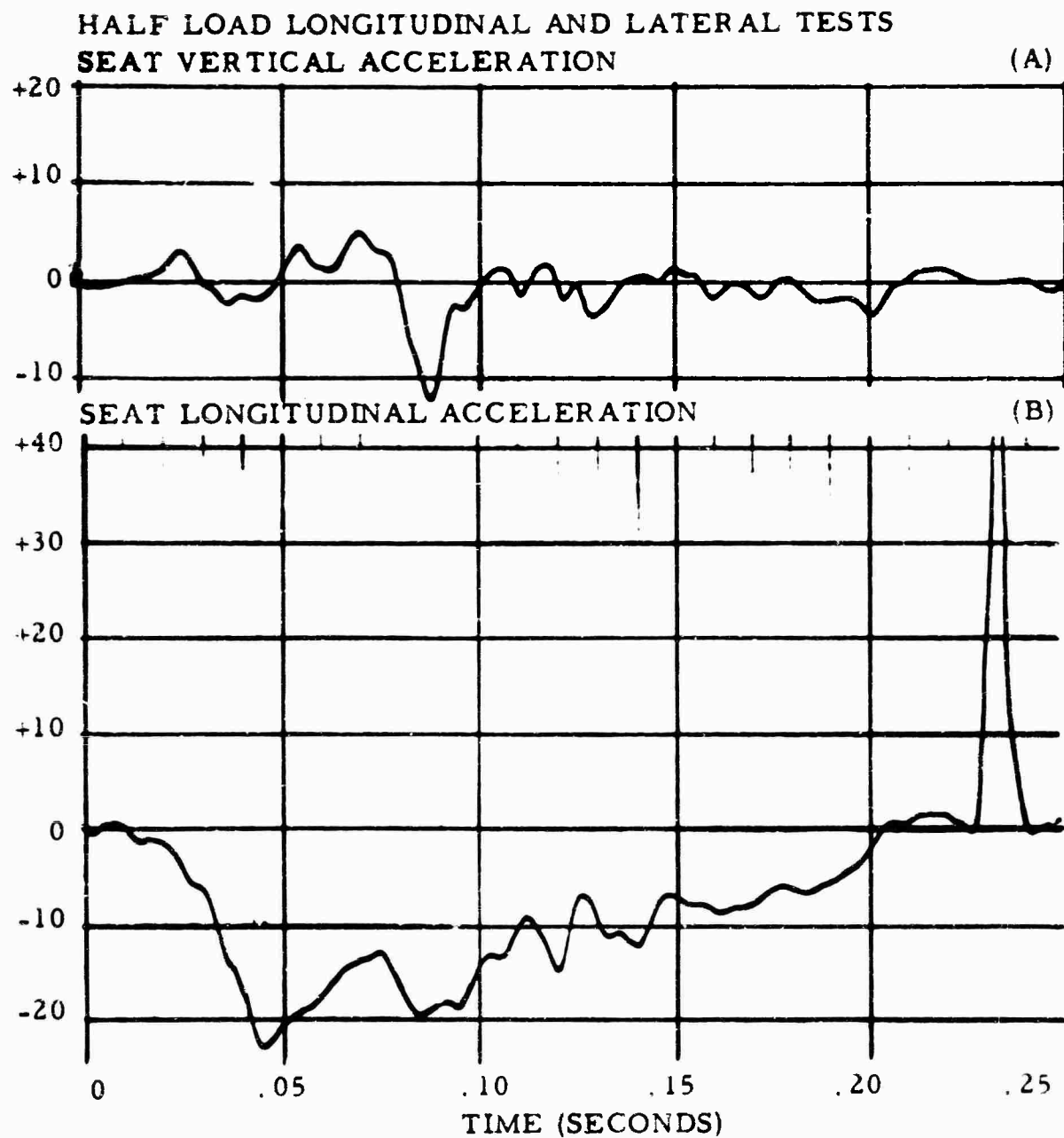Figure 16. Posttest View of Bell Seat - Test Condition No. 2.

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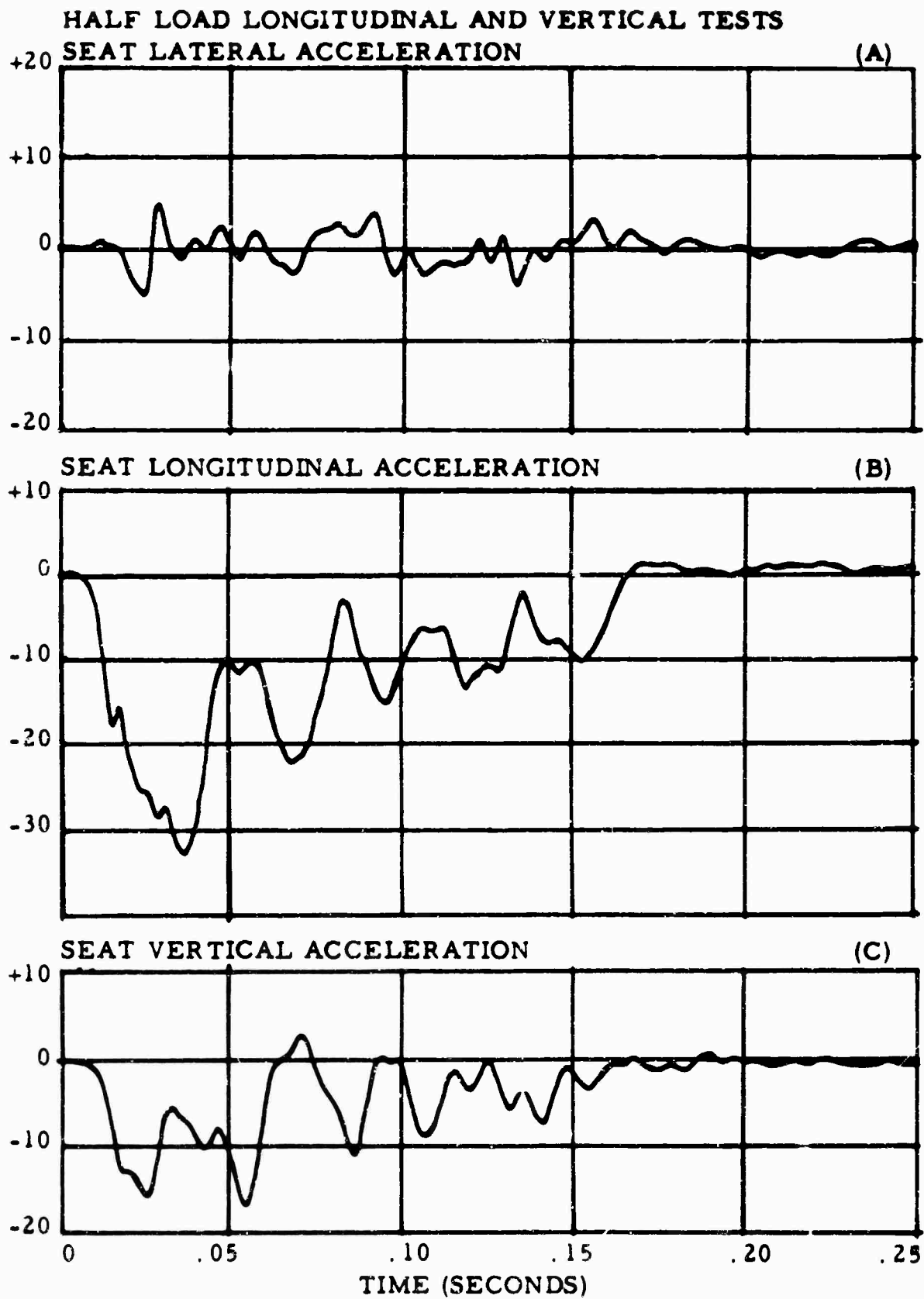
Figure 17. Data Time Histories - Bell Seat - Test Condition No. 1.

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HALF LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY LATERAL ACCELERATION (D)
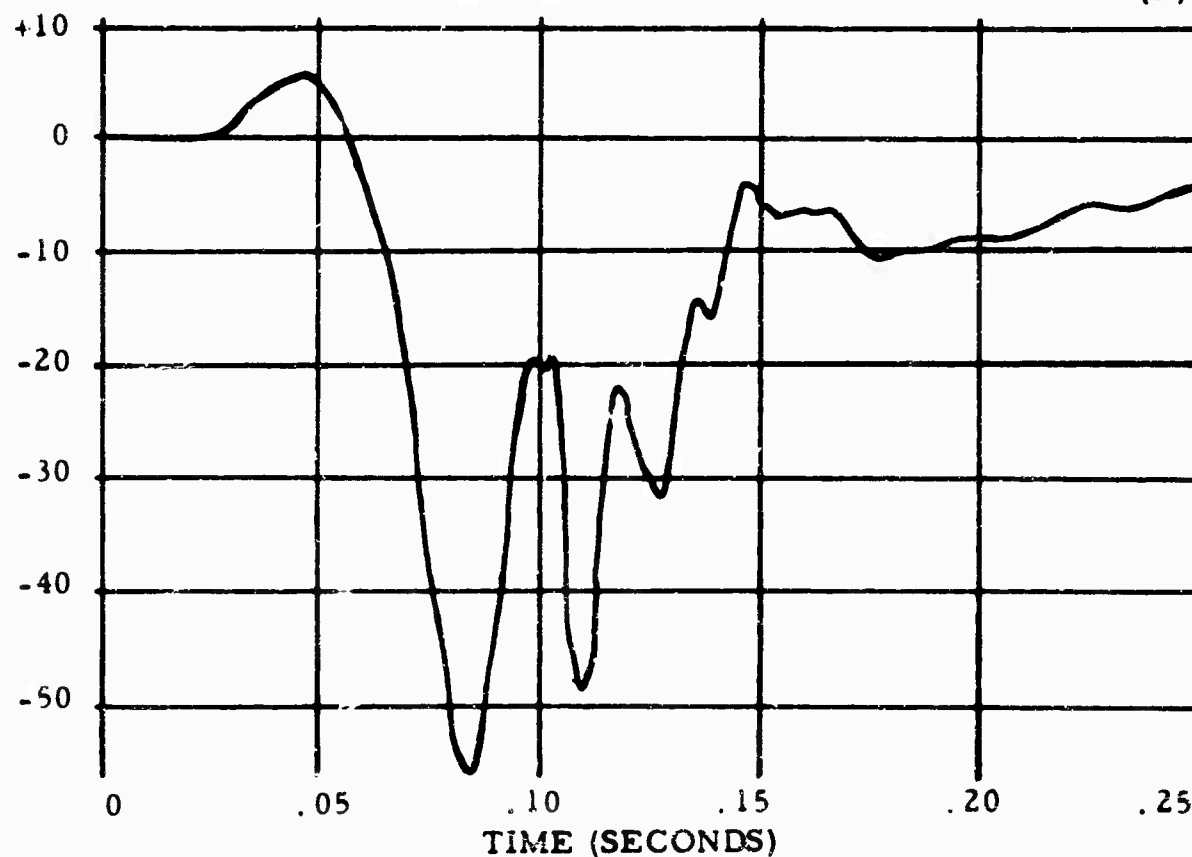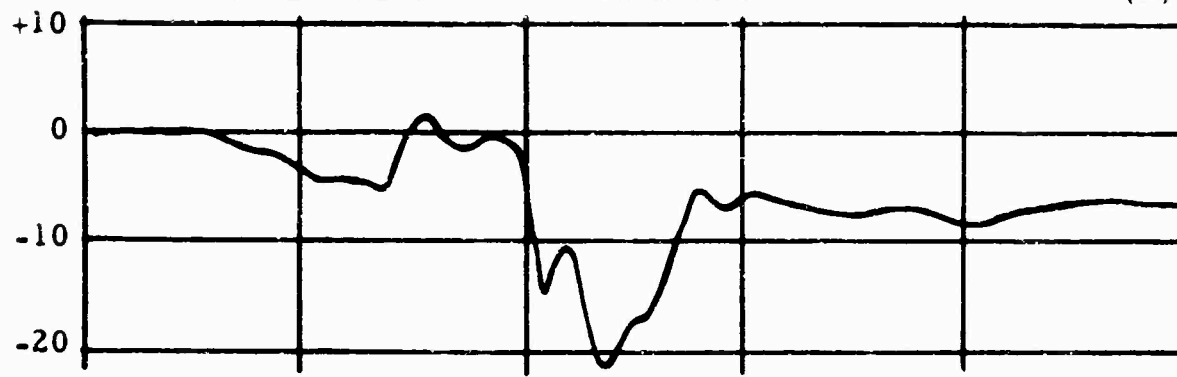

DUMMY LONGITUDINAL ACCELERATION (E)

TIME (SECONDS)

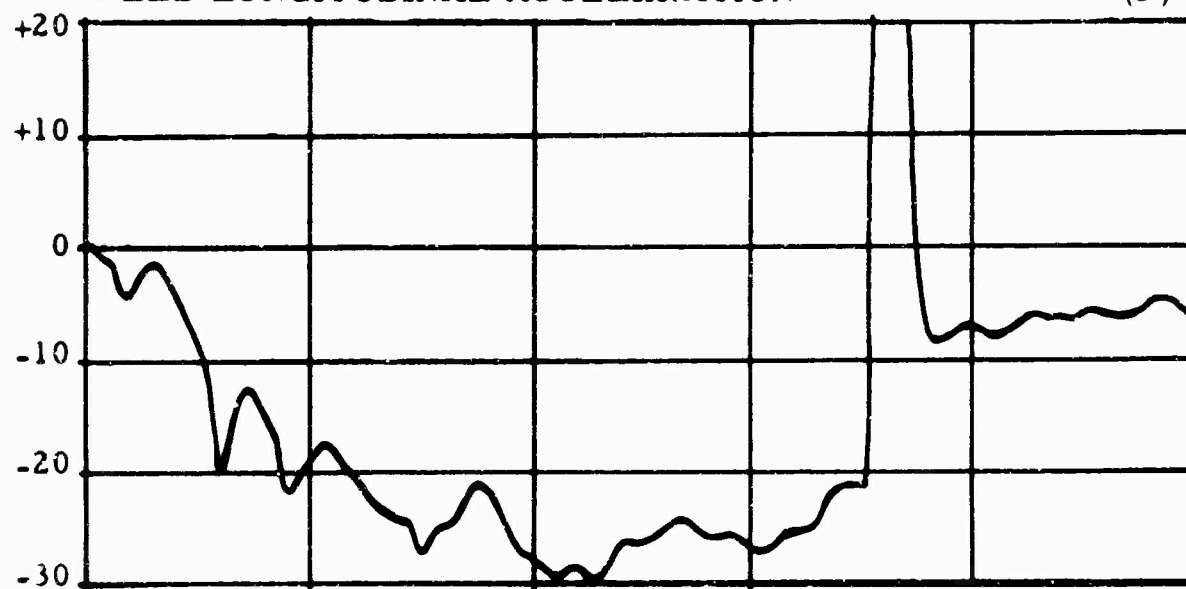Figure 17 (contd.). Data Time Histories - Bell Seat - Test Condition No. 1.

HALF LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY VERTICAL ACCELERATION (F)

SLED LONGITUDINAL ACCELERATION (G)

TIMF (SECONDS)

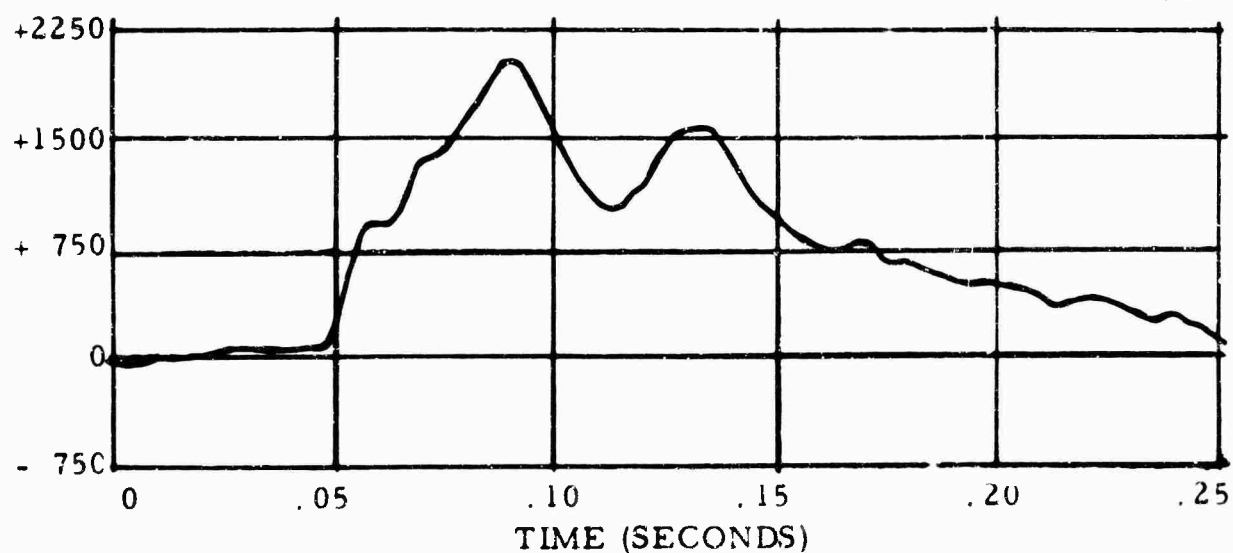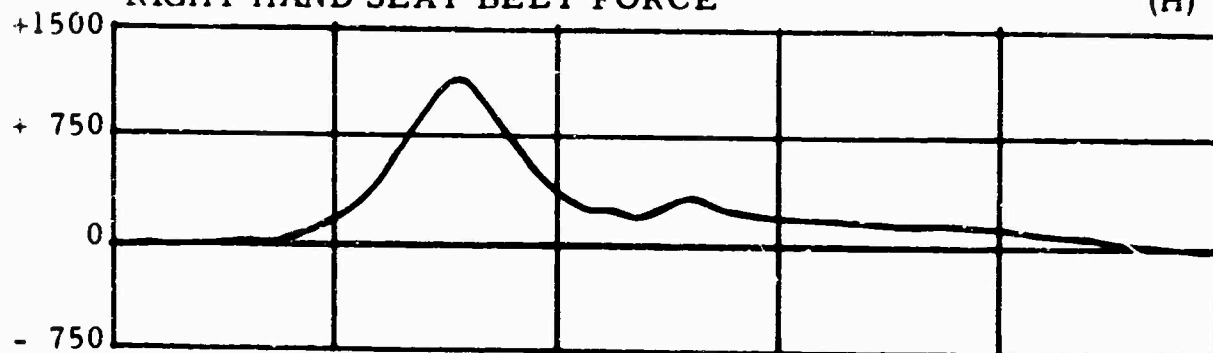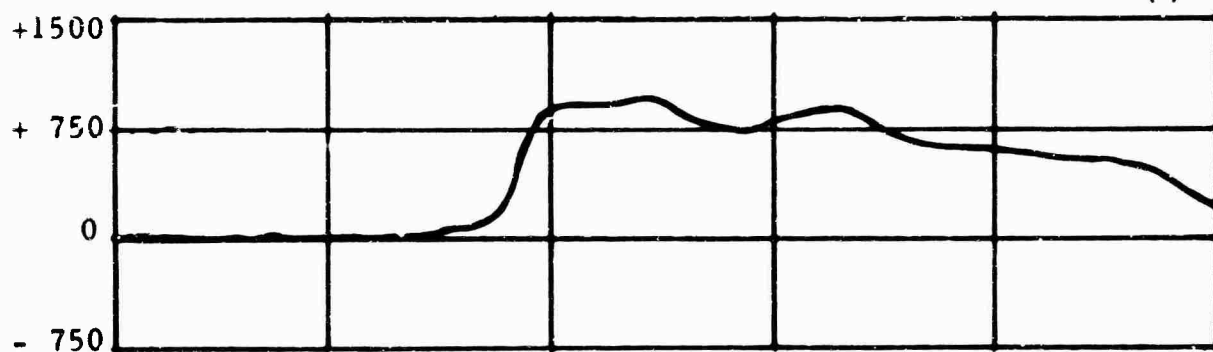Figure 17 (contd.)   Data Time Histories - Bell Seat -
Test Condition No. 1.

HALF LOAD LONGITUDINAL AND VERTICAL TESTS
RIGHT HAND SHOULDER HARNESS FORCE   (H)

LEFT HAND SHOULDER HARNESS FORCE   (I)

RIGHT HAND SEAT BELT FORCE   (J)
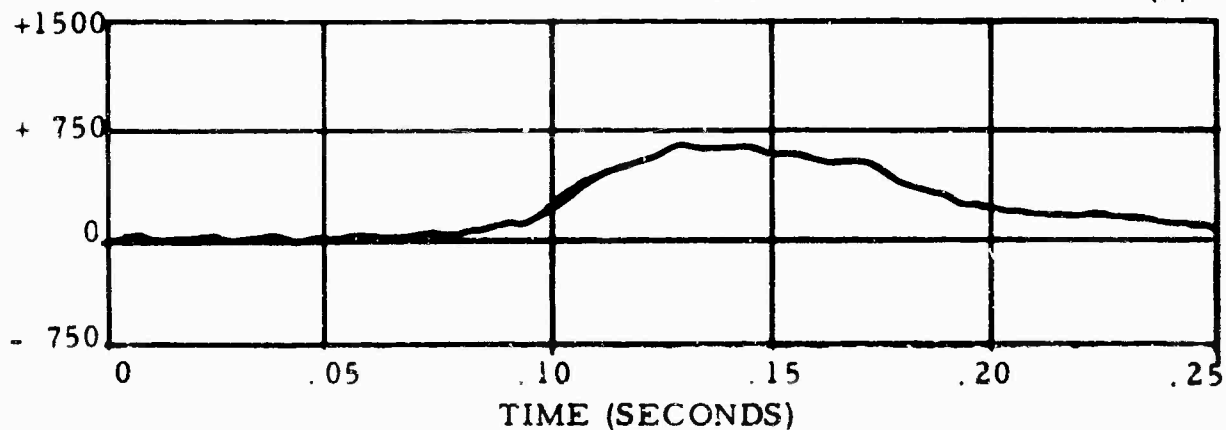
TIME (SECONDS)

Figure 17 (contd.). Data Time Histories - Bell Seat - Test Condition No. 1.

32
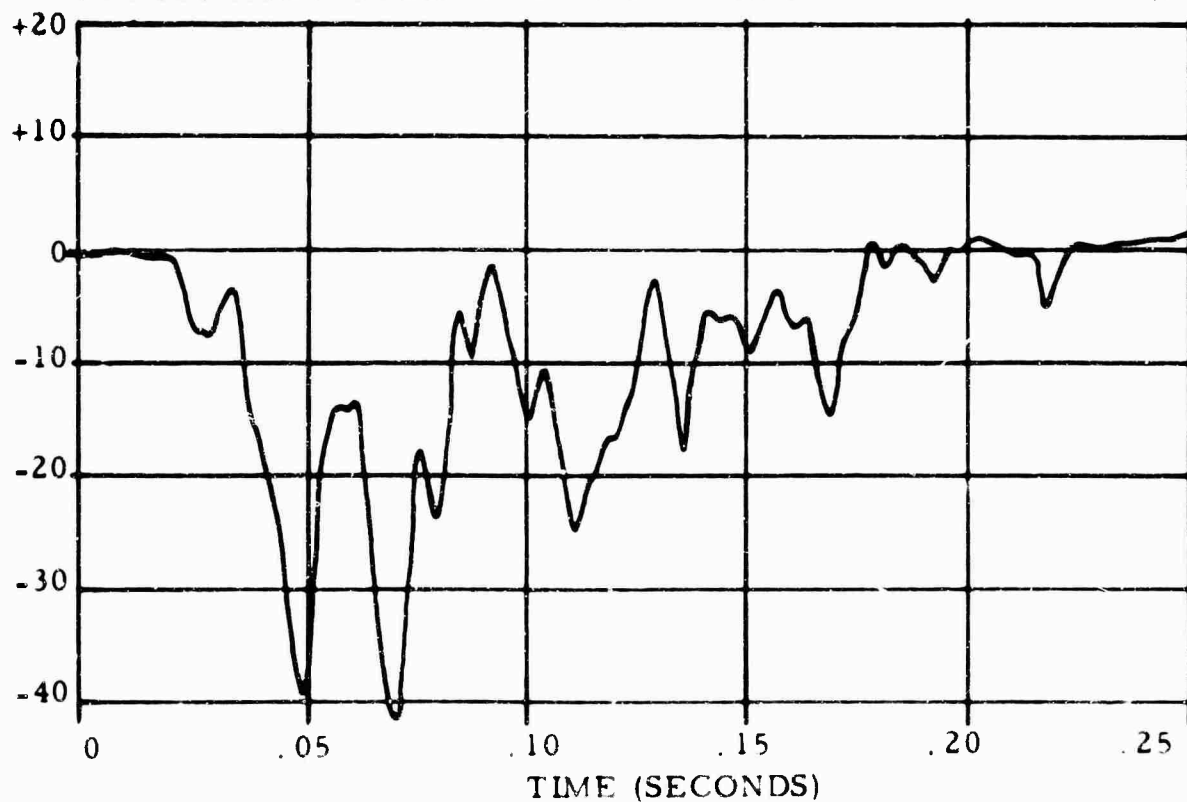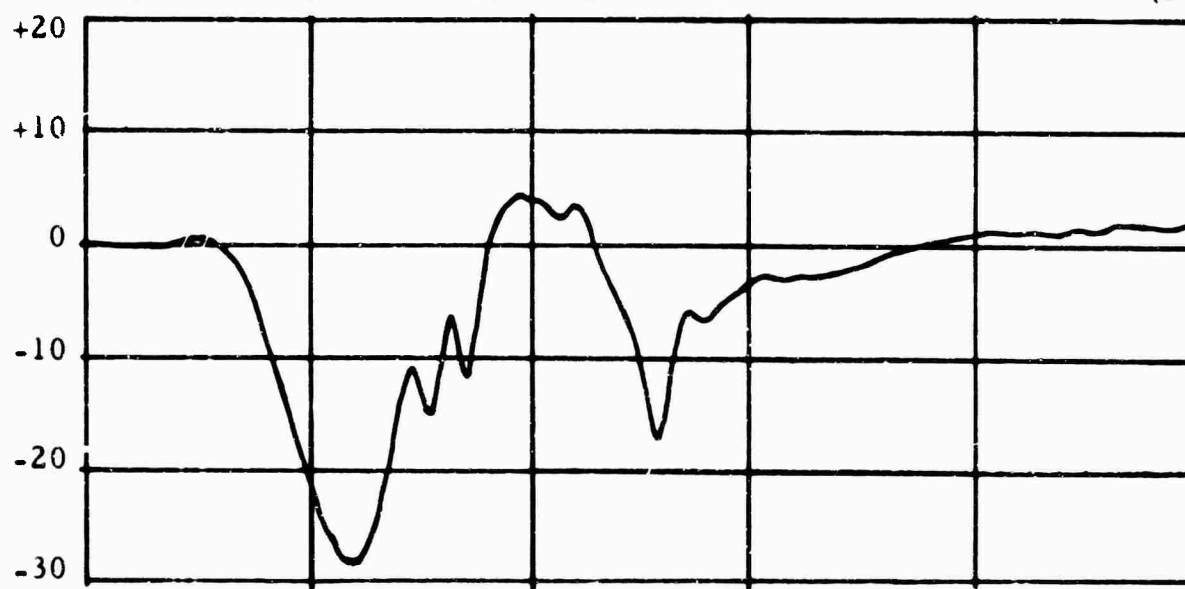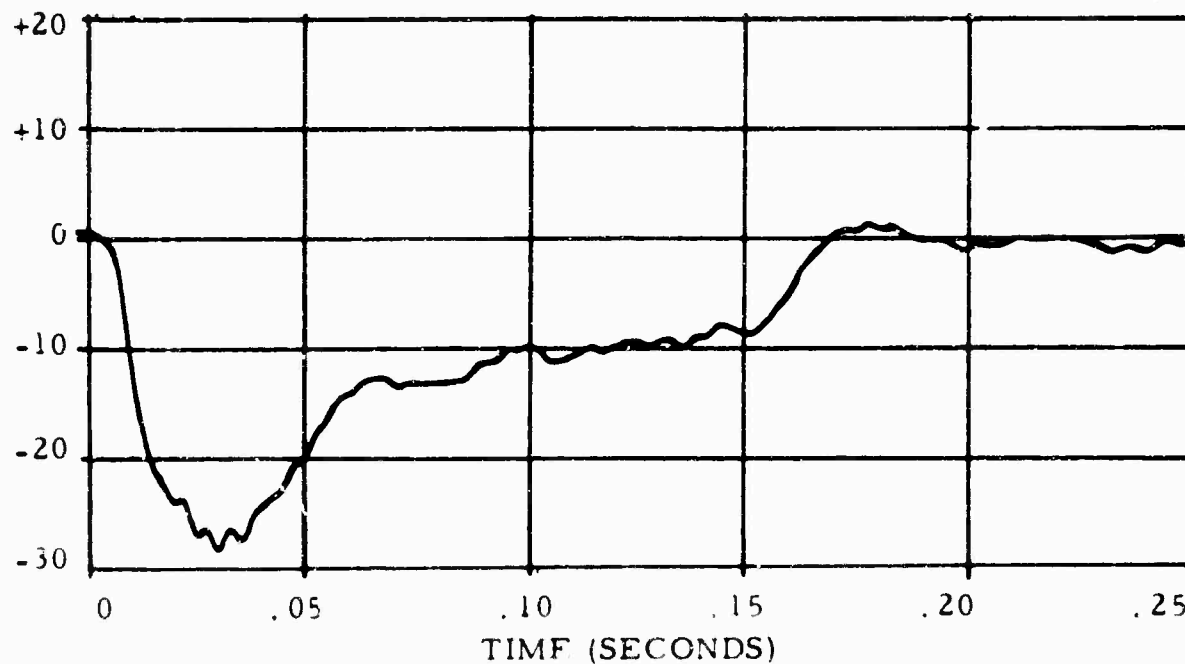
HALF LOAD LONGITUDINAL AND VERTICAL TESTS
FORWARD RIGHT HAND SEAT LEG FORCE   (K)

Figure 17 (contd.). Data Time Histories - Bell Seat -
Test Condition No. 1.

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HALF LOAD LONGITUDINAL AND VERTICAL TESTS
FORWARD LEFT HAND SEAT LEG FORCE (L)
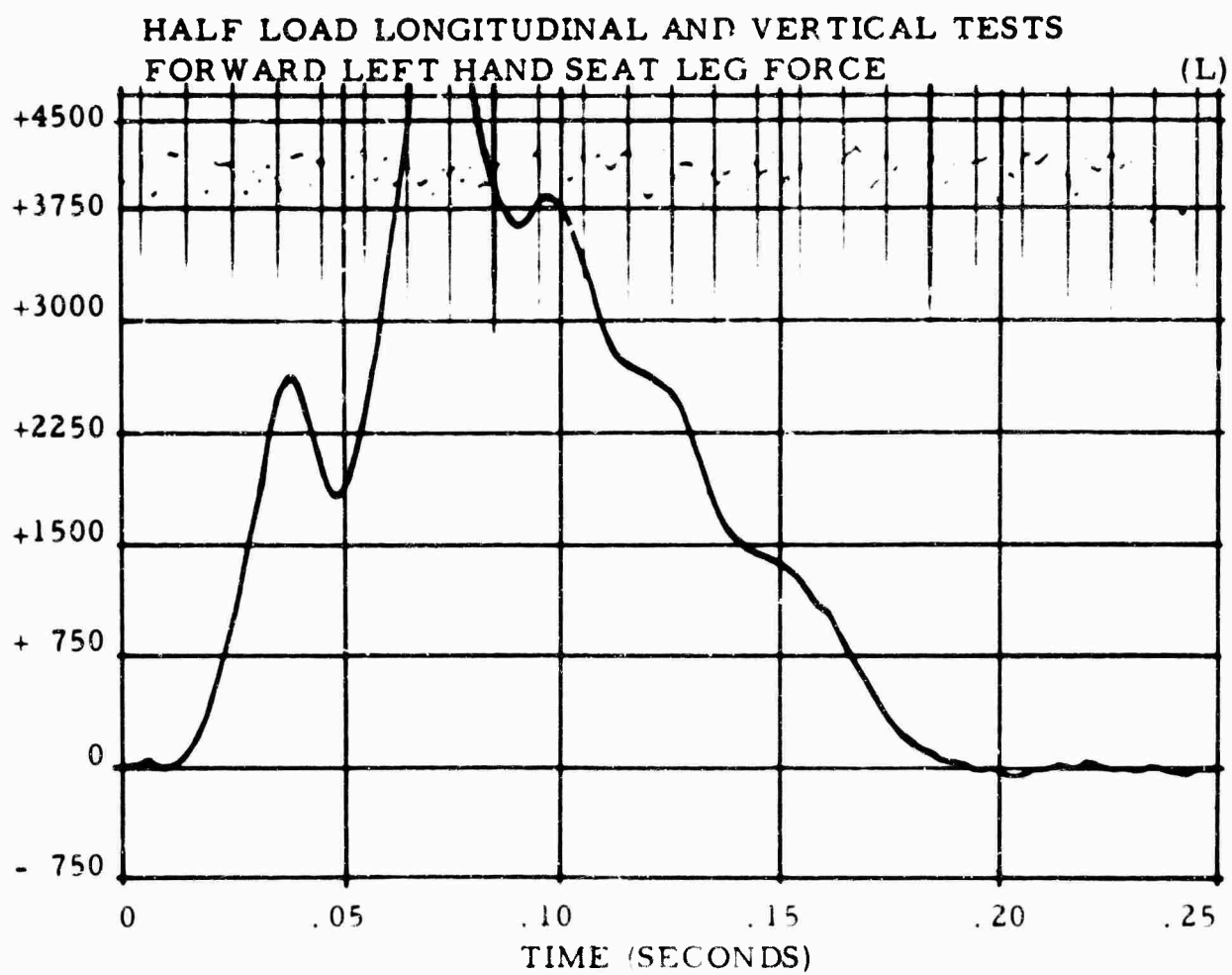
Figure 17 (contd.). Data Time Histories - Bell Seat -
Test Condition No. 1.

Figure 17F shows a dynamic amplification of 2.4 (26G ÷ 11G) for the vertical deceleration for the dummy. This "overshoot" is probably due to cushion deflection coupled with internal deflection in the dummy itself. The dummy longitudinal record was obtained in this test and is presented but not discussed because of an apparent instrument malfunction.

The seat belt and shoulder harness loads are shown in Figure 17H, I, and J and are considerably lower than in the longitudinal-lateral test, as would be anticipated with a large vertical component.

BELL SEAT TEST CONDITION NO. 2

Under this test condition, the seat was oriented 28 degrees laterally from the sled thrust line, as shown in Figure 14. The dummy remained stationary as the sled began to accelerate; sled movement of approximately 18 inches resulted before the dummy began to move. During this movement, the chest armor plate was pushed away from the dummy; and upon reaching its maximum permissible distance, it failed and jettisoned, as designed, at approximately 0.055 second. Figure 16 is a posttest view of the Bell seat, and visual examination of the seat indicated no apparent damage.

The "target" or intent pulse was trapezoidal with 25G plateau lasting for 0.10 second. This would give a seat acceleration of 22.5G longitudinal and 12.5G lateral. The actual condition, shown in Figure 18G, was a basically trapezoidal pulse with an average magnitude of 19G and a peak G reading of 24G. The 19G plateau was maintained for about 0.11 second, and the total pulse duration was approximately 0.20 second. Figure 18 shows that the seat longitudinal acceleration follows the sled acceleration closely as would be anticipated for a rigid seat. Note from Figure 14 that the seat longitudinal G will theoretically be equal to the sled G multiplied by the cosine of 28 degrees, assuming no elasticity of the seat. A comparison of Figures 18 F and 18 B indicates that this relationship was approximately maintained. The seat lateral acceleration indicated an instrument malfunction; however, it can safely be assumed to have been 45 percent (sine 28 degrees = 0.45) of the sled acceleration (since good agreement exists between the theoretical longitudinal and actual longitudinal data).

Figures 18 C and 18D, which give the dummy pelvic lateral and longitudinal accelerations, are of particular importance. Observation of these plots quickly shows that the dummy does not accelerate in phase with the seat

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HALF LOAD LONGITUDINAL AND LATERAL TESTS

SEAT VERTICAL ACCELERATION (A)

SEAT LONGITUDINAL ACCELERATION (B)

TIME (SECONDS)

Figure 18. Data Time Histories - Bell Seat - Test Condition No. 2.
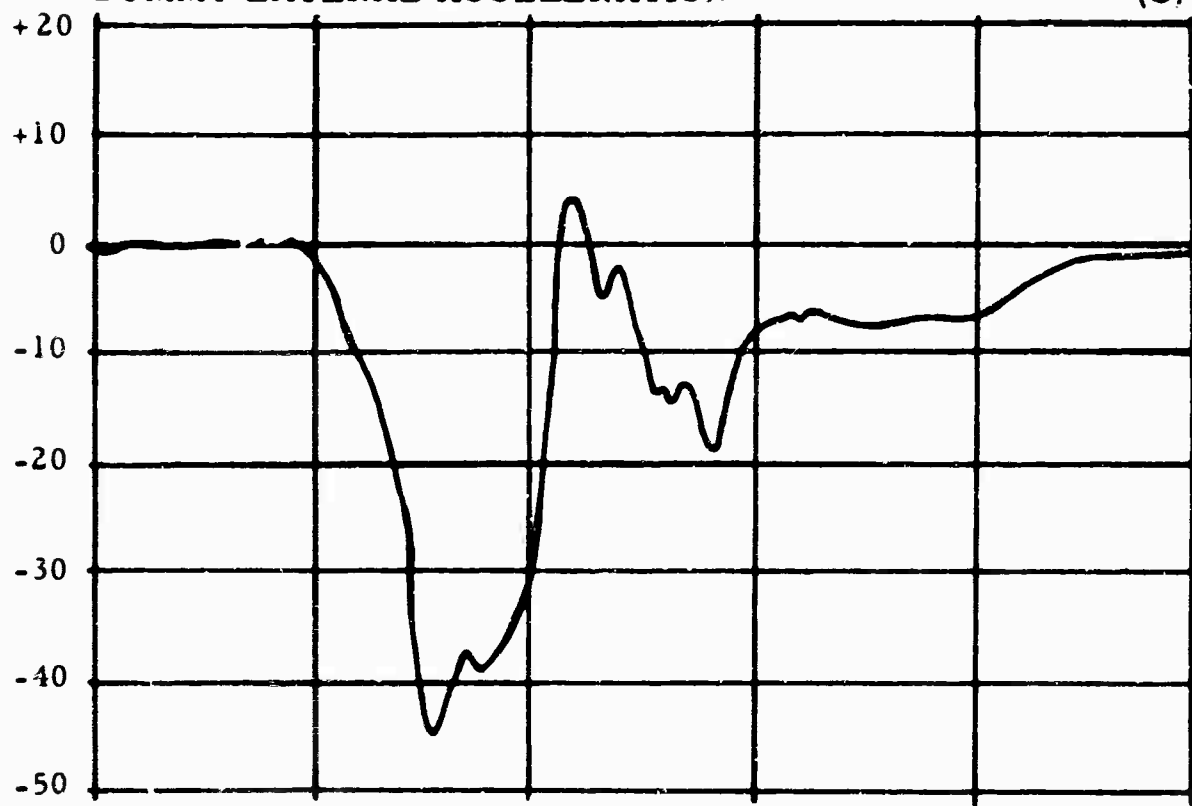
Figure 18 (contd.). Data Time Histories - Bell Seat -
Test Condition No. 2.

HALF LOAD LONGITUDINAL AND LATERAL TESTS
DUMMY VERTICAL ACCELERATION (E)

SLED LONGITUDINAL ACCELERATION (F)

LEFT HAND SEAT BELT FORCE (G)

TIME (SECONDS)

Figure 18 (contd.). Data Time Histories – Bell Seat –
Test Condition No. 2.

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HALF LOAD LONGITUDINAL AND LATERAL TESTS
RIGHT HAND SEAT BELT FORCE
(H)

RIGHT HAND SHOULDER HARNESS FORCE
(I)

LEFT HAND SHOULDER HARNESS FORCE
(J)

TIME (SECONDS)

Figure 18 (contd.). Data Time Histories - Bell Seat -
Test Condition No. 2.

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HALF LOAD LONGITUDINAL AND LATERAL TESTS
FORWARD RIGHT HAND SEAT LEG FORCE   (K)
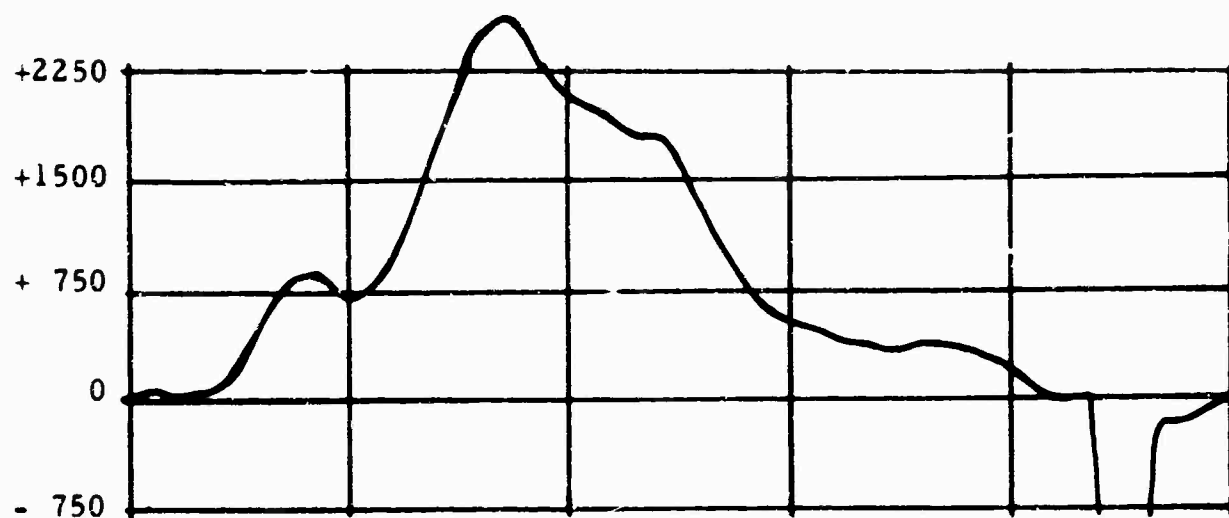
FORWARD LEFT HAND SEAT LEG FORCE   (L)

TIME (SECONDS)

Figure 18 (contd.). Data Time Histories - Bell Seat -
Test Condition No. 2.
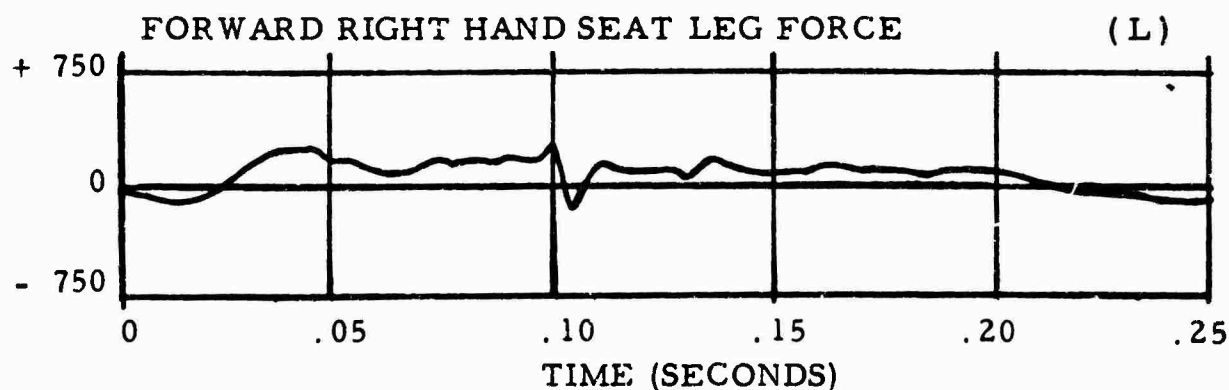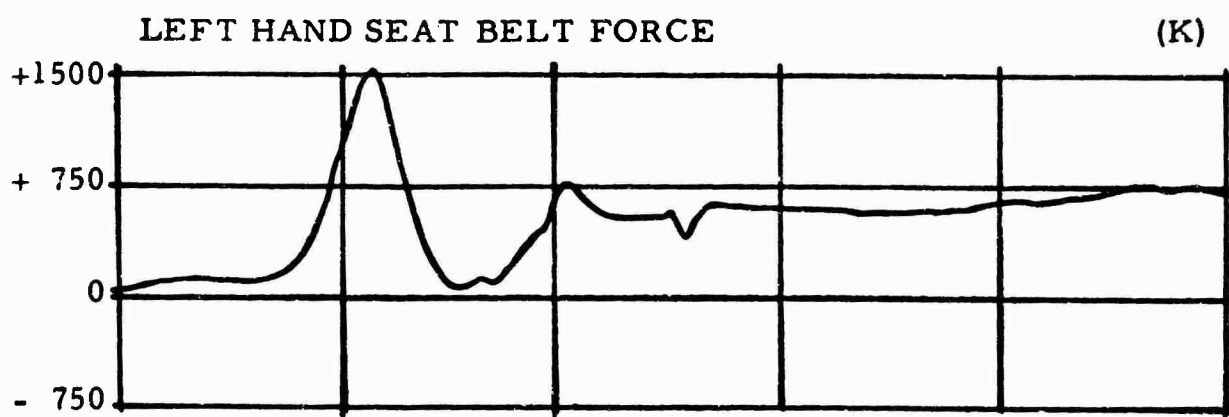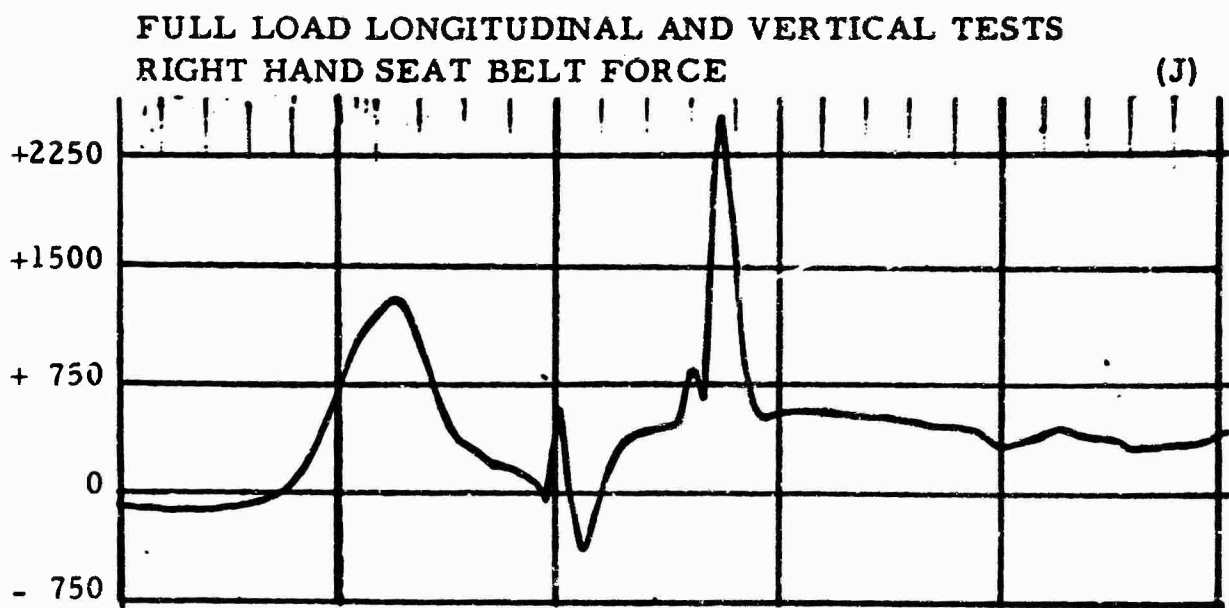
40
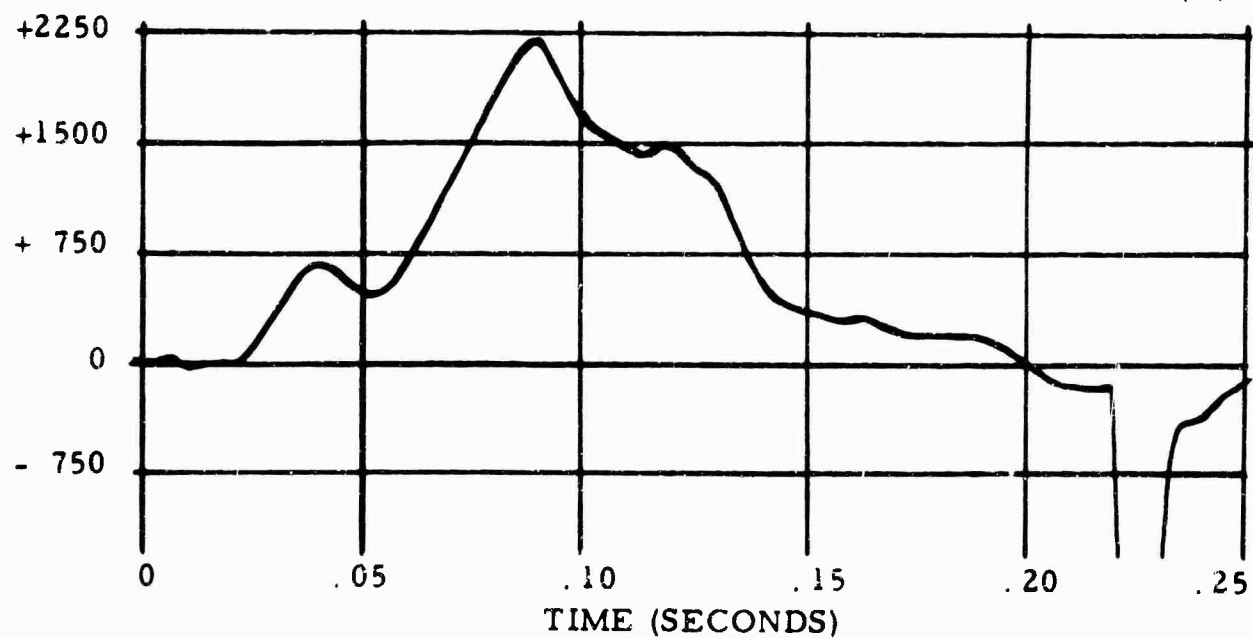
and at the same rate as the sled and seat. A; shown by the "average" curve in Figure 18D, the acceleration of the dummy reached a maximum of about 40G, which gives a peak dynamic amplification factor of in excess of 2.5. The response of the dummy, as seen in the high-speed films, bears out this fact. The high G values are caused by the excessive extension of the seat belt and shoulder harness. This allows the dummy to attain a velocity relative to the seat until it is rapidly decelerated by the extended harness.

Figures 18I and 18J give the shoulder harness loads which peak at 2000 pounds (left hand) and about 1500 pounds (right hand) in phase with the peak longitudinal accelerations of the dummy. These loads are of the correct order of magnitude to place 40G on the upper torso.

BELL SEAT TEST CONDITION NO. 3

This test was a full-load test with the seat oriented 28 degrees upward from the horizontal, as shown in Figure 14. Visual examination of the seat after the test showed failures in both the front and rear seat legs. Analysis of the high-speed film was necessary to ascertain the sequence of the failure. This sequence is shown in Figure 19. The first failure occurred at the attachment of the top of the rear legs to the upper cross-bar because of the stripping of the threads in the aluminum fitting at the top of the rear legs. These failures can be seen occurring at approximately 0.06 second in the series of sequence photographs of Figure 19. This failure destroyed the rigidity of the triangular structure formed by the legs and lower track. The seat pan and rear legs then rotated forward, ultimately causing a shear failure in the lower right rear leg attachment bolt and a fracture of the lower end of the left rear leg. The buckling of the front legs was caused by a safety cable which was installed to allow the dummy free movement but to prevent the dummy from completely leaving the sled in event of a seat or retention system failure. When the rear legs failed, the seat and dummy moved forward far enough to stress the safety cable, which then broke the dummy in half and collapsed the forward legs of the seat. Figures 20 and 21 illustrate the failures described above. The seat had to fail prior to contact with the restraining cable. The data subsequent to contact with the cable would not be representative of t - seat.

The sled acceleration pulse for this test is shown in Figure 22G. As noted in the figure, an instrumentation disconnect occurred at approximately 0.09 second. The complete sled acceleration pulse has been reconstructed and plotted in the figure from the main-cylinder steam-pressure curve which was obtained through a separate set of cables,

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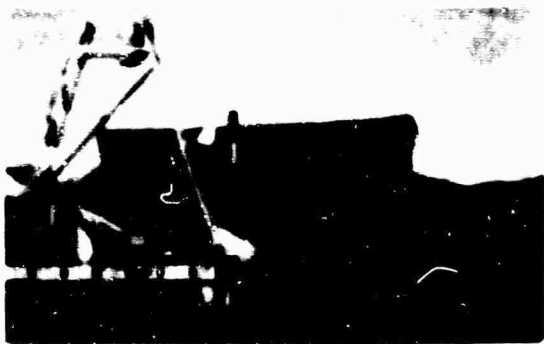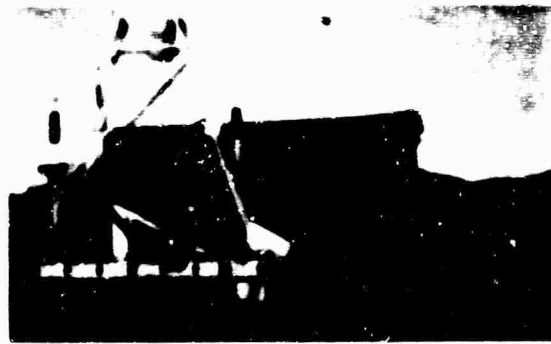
t = 0.0 sec.; first motion   t = 0.034 sec.; sled movement, 1 ft.

t = 0.050 sec.; sled movement, 2 ft.   t = 0.061 sec.; sled movement, 3 ft.
                                        (rear seat leg has failed)
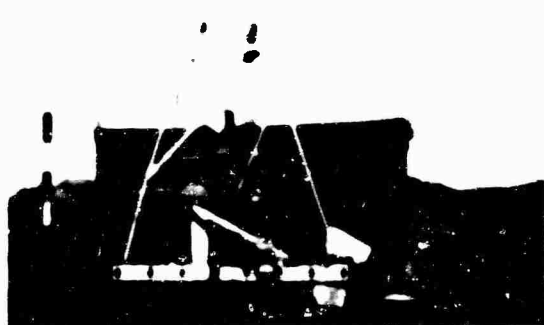
t = 0.072 sec.; sled movement, 4 ft.   t = 0.081 sec.; sled movement, 5 ft.

t = 0.090 sec.; sled movement, 5 ft. 10 in.
(instrumentation has disconnected)

Figure 19. Sequence Photographs of Bell Seat - Test Condition No. 3.

Figure 20. Posttest View of Bell Seat - Test Condition No. 3.
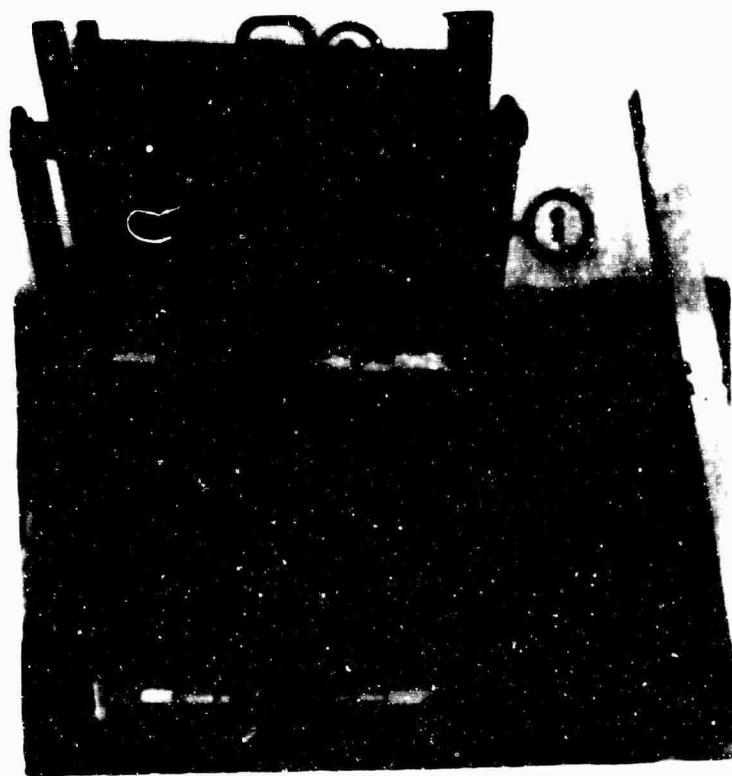
Figure 21. Damage to Back Frame of Bell Seat - Test Condition No. 3.

FULL LOAD LONGITUDINAL AND VERTICAL TESTS
SEAT LATERAL ACCELERATION

SEAT LONGITUDINAL ACCELERATION

TIME (SECONDS)
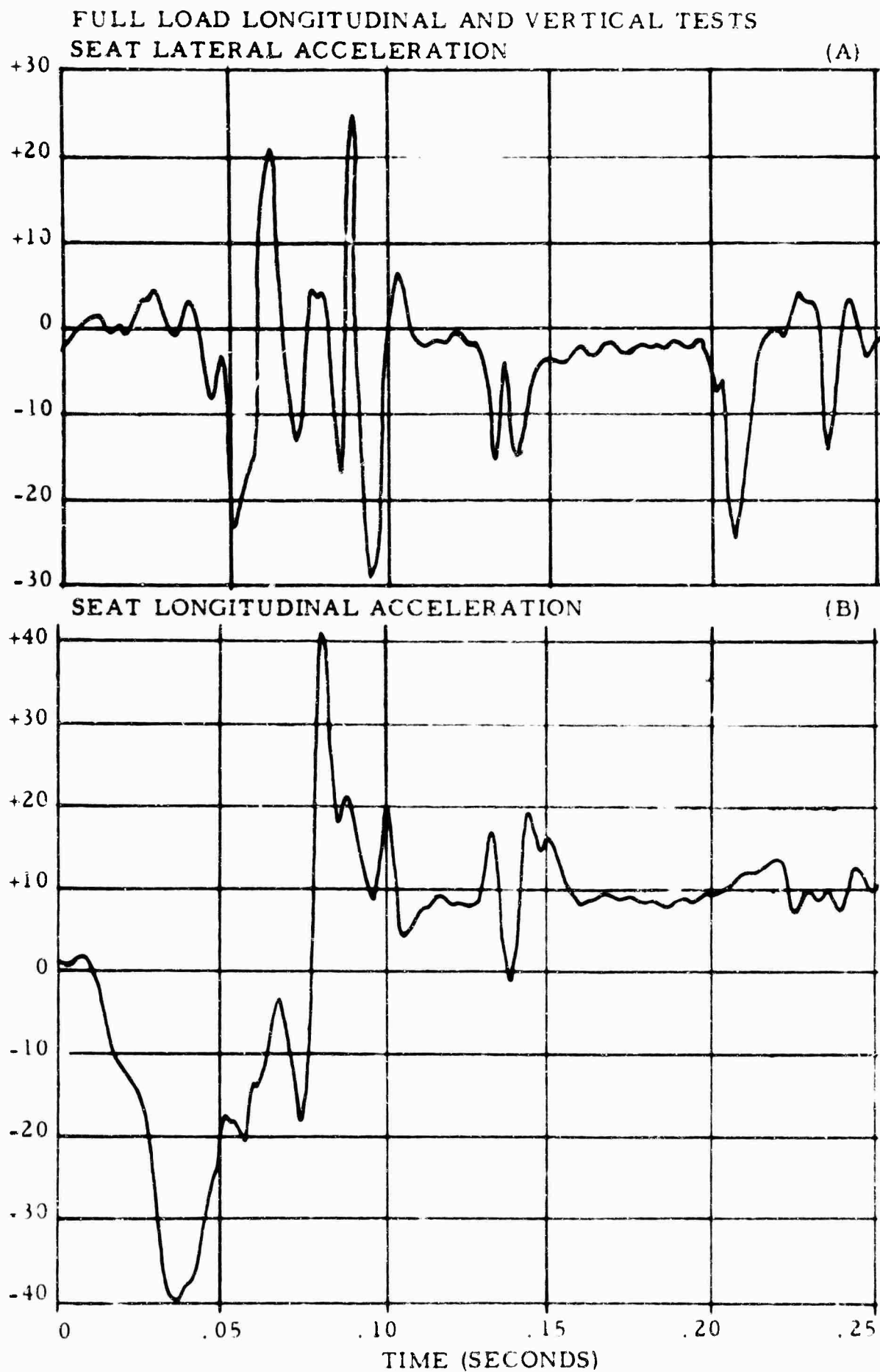
Figure 22. Data Time Histories - Bell Seat -
Test Condition No. 3.

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FULL LOAD LONGITUDINAL AND VERTICAL TESTS
SEAT VERTICAL ACCELERATION   (C)

DUMMY LATERAL ACCELERATION   (D)

TIME (SECONDS)

Figure 22 (contd.). Data Time Histories - Bell Seat -
Test Condition No. 3.

45
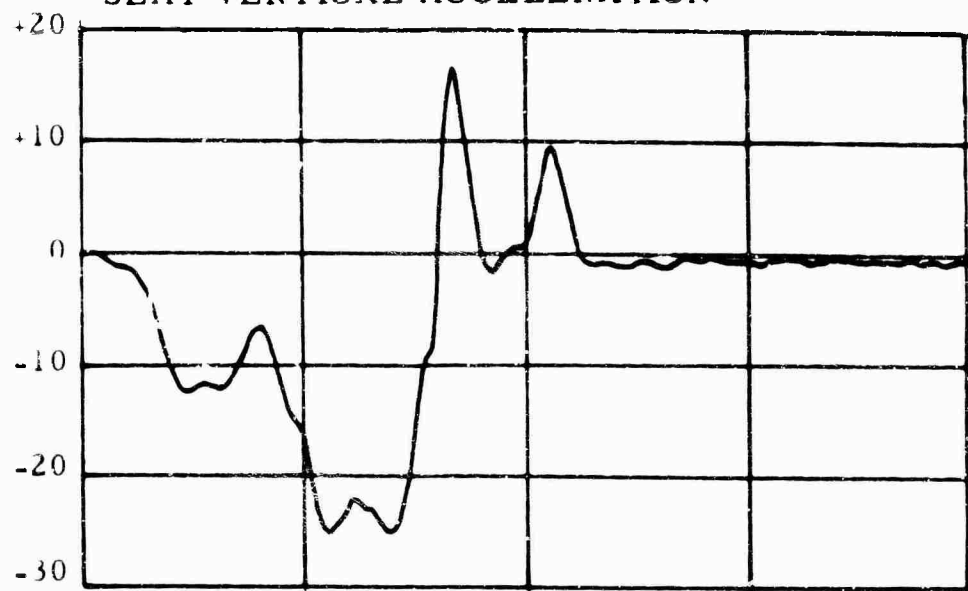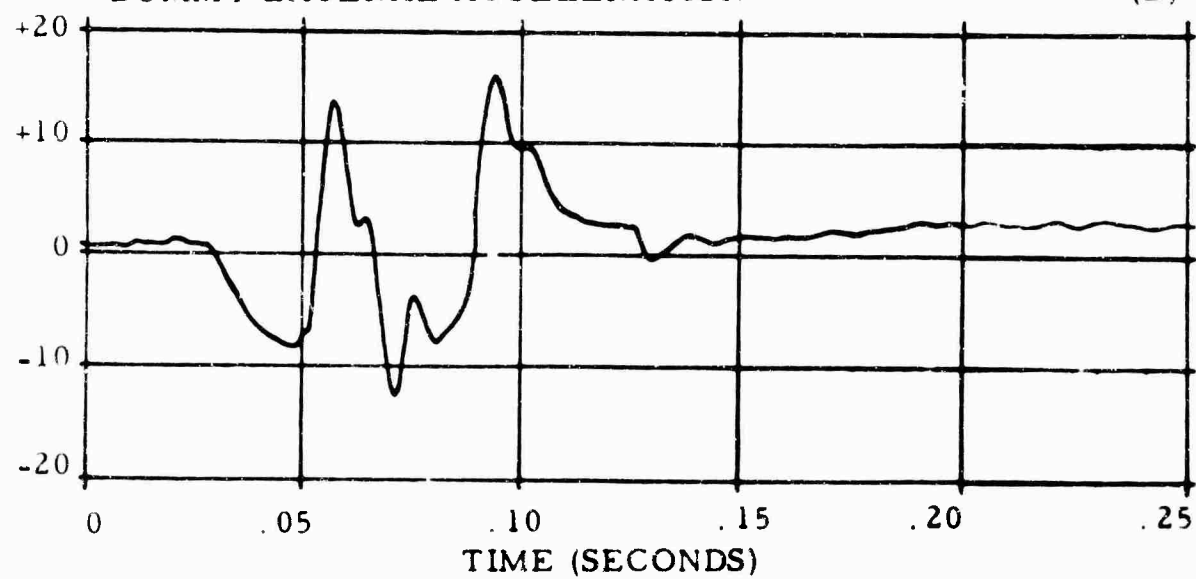
FULL LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY LONGITUDINAL ACCELERATION   (E)
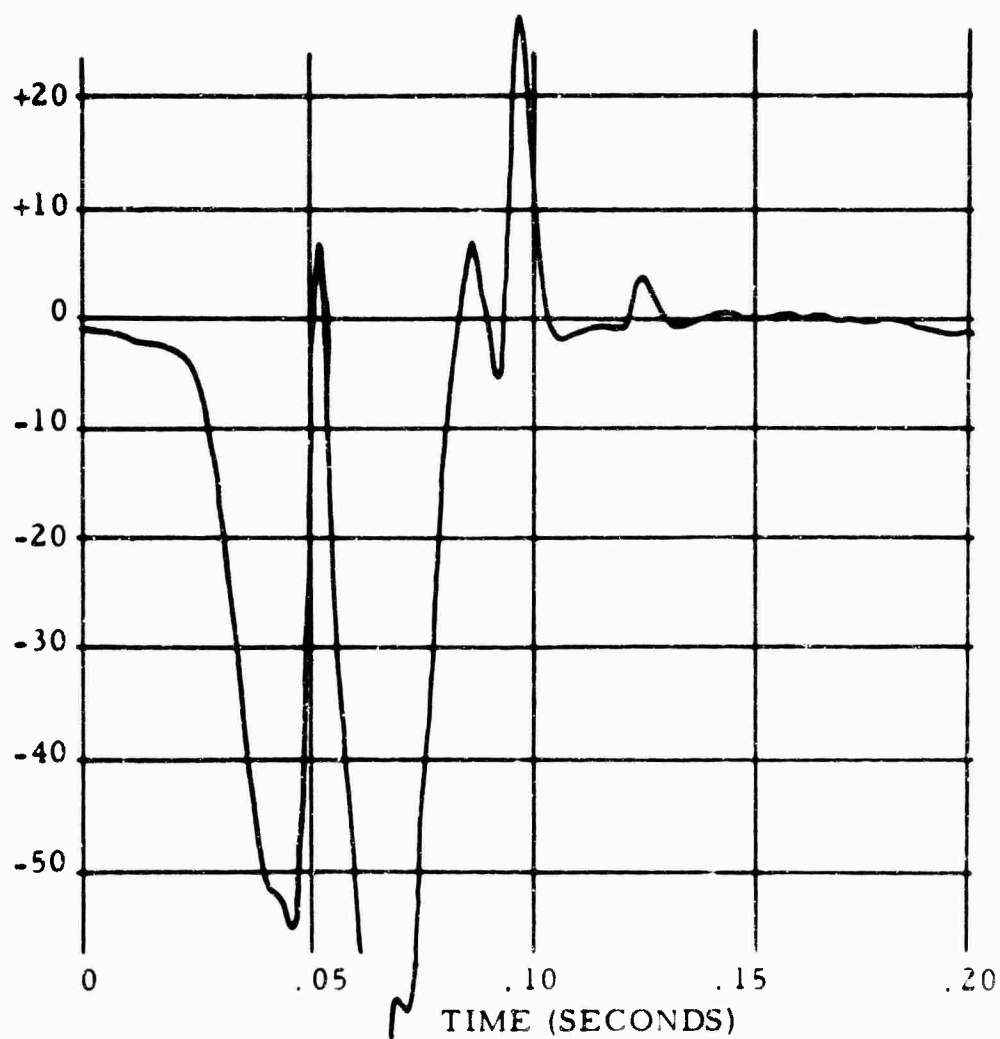
Figure 22 (contd.). Data Time Histories - Bell Seat -
Test Condtion No. 3.

FULL LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY VERTICAL ACCELERATION   (F)

Figure 22 (contd.). Data Time Histories - Bell Seat - Test Condition No. 3.

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Figure 22 (contd.). Data Time Histories - Bell Seat -
Test Condition No. 3.

FULL LOAD LONGITUDINAL AND VERTICAL TESTS
RIGHT HAND SEAT BELT FORCE (J)

LEFT HAND SEAT BELT FORCE (K)

FORWARD RIGHT HAND SEAT LEG FORCE (L)

TIME (SECONDS)

Figure 22 (contd.). Data Time Histories - Bell Seat - Test Condition No. 3.

49
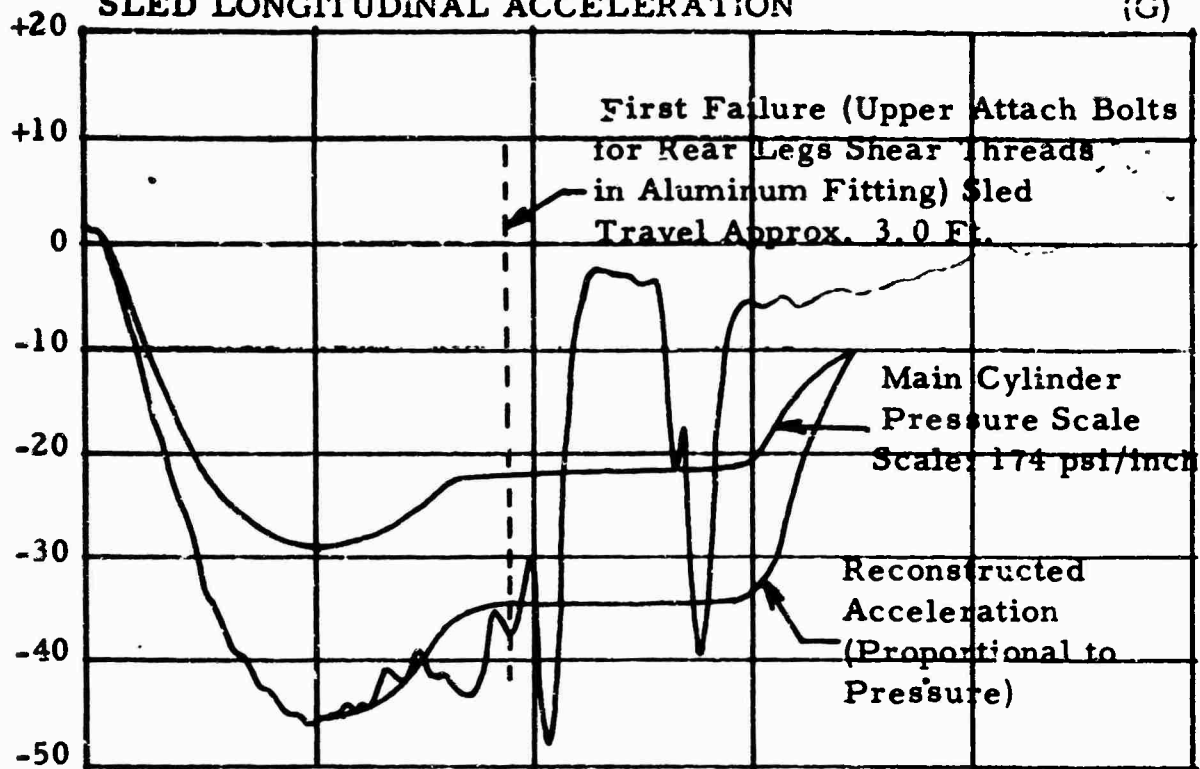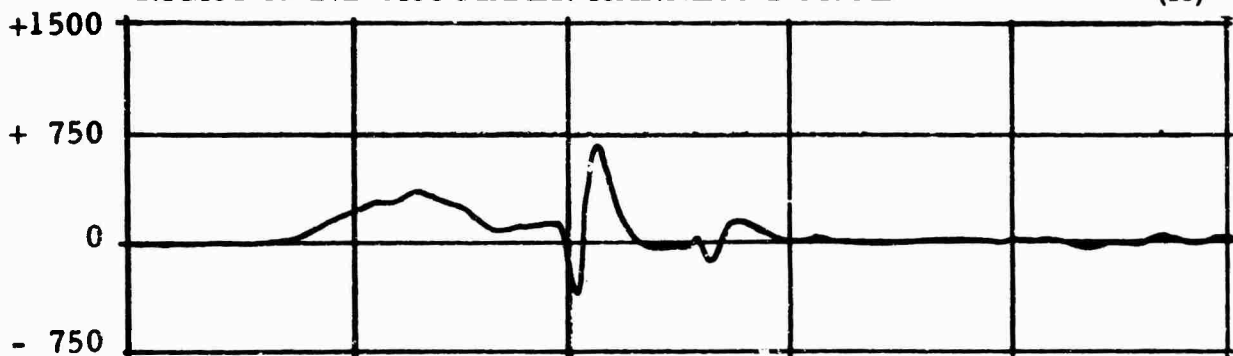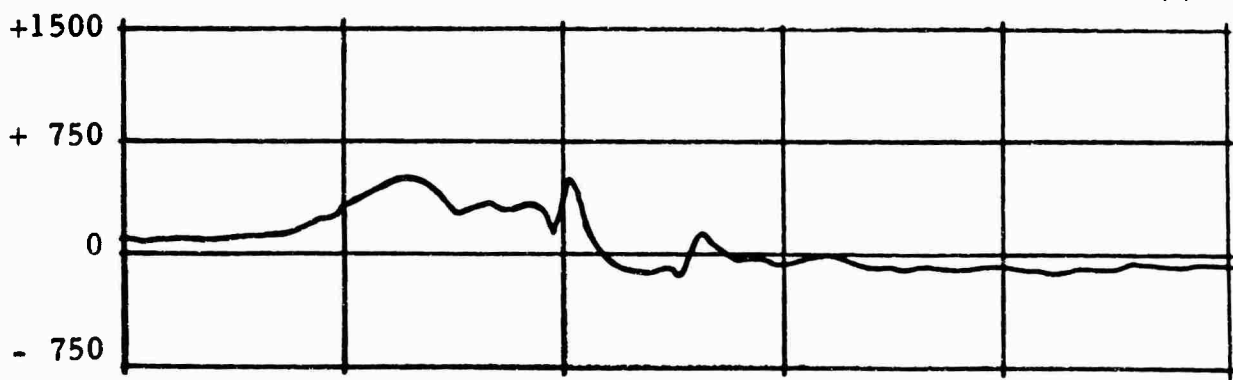
FULL LOAD LONGITUDINAL AND VERTICAL TESTS
FORWARD LEFT HAND SEAT LEG FORCE   (M)
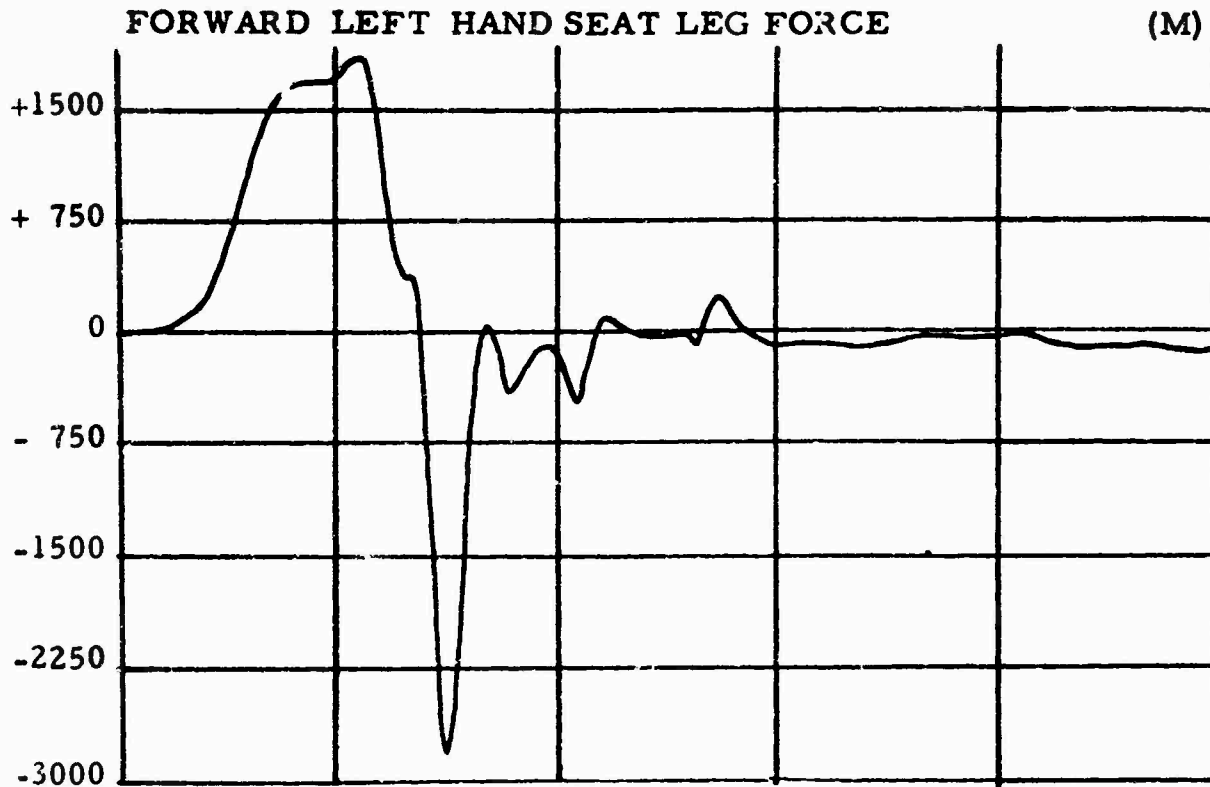
AFT RIGHT HAND SEAT LEG FORCE   (N)
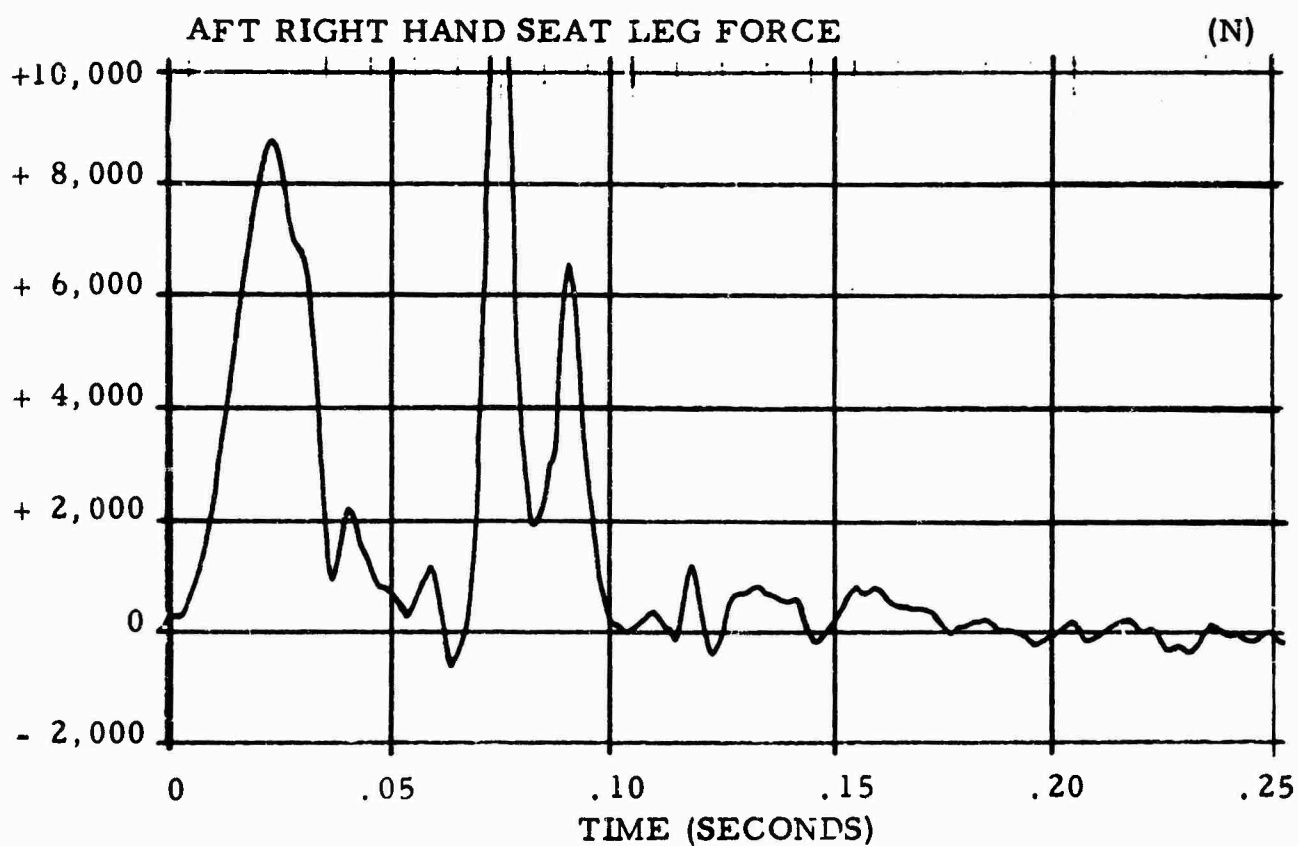
TIME (SECONDS)

Figure 22 (contd.). Data Time Histories - Bell Seat -
Test Condition No. 3.

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FULL LOAD LONGITUDINAL AND VERTICAL TESTS
AFT LEFT HAND SEAT LEG FORCE   (O)

Figure 22 (contd.). Data Time Histories - Bell Seat -
Test Condition No. 3.

51
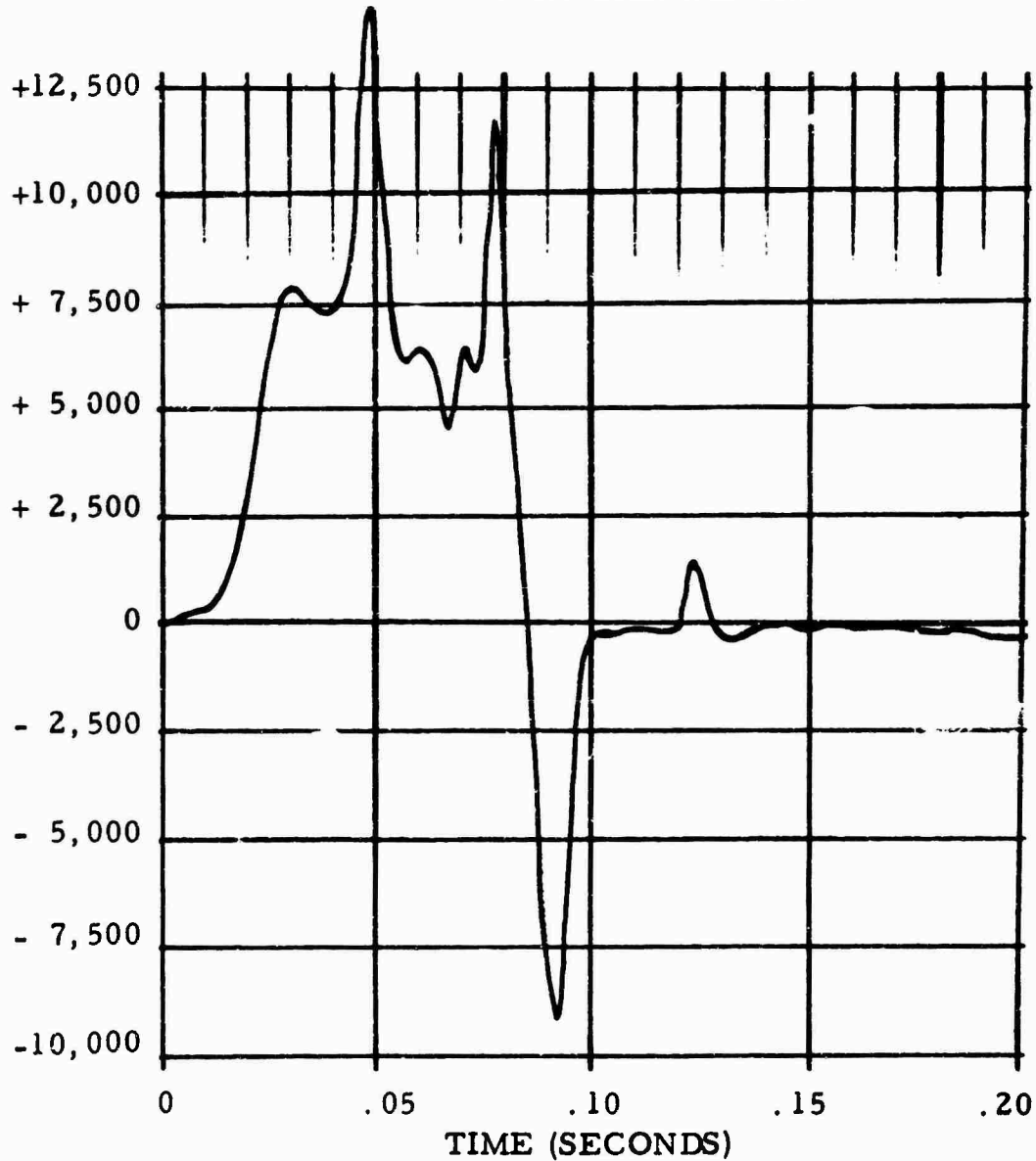
unaffected by the primary instrumentation disconnect. In all cases where both pressures and sled acceleration curves were obtained, extremely close agreement was evident in the shapes and durations of these curves. This is necessarily true since approximately 95 percent of the load applied to the sled is of the steam pressure against the movable piston; friction and air resistance account for the remainder. For example, in Figure 22, the maximum recorded acceleration (t = 0.05 second) was 41G. The steam pressure recorded was 220 psi at this time. For the 23.5-inch-diameter piston and the sled weight of 2200 pounds, the computed acceleration would be:

$$G = \frac{F}{W} = \frac{(3.14)\,(23.5)^2 \times 220}{4 \times 2200} = 43G,$$

thus giving excellent agreement.

The early instrumentation disconnect occurred in all of the full-load tests and, while not intended, did not result in loss of data in the tests of the Bell, Vertol, and Kaman seats, since failure occurred in these systems prior to disconnect. Complete records would have been valuable in the Sikorsky seat test and, in the case of the combination longitudinal-vertical, were nearly obtained.

The disconnect occurred because the forces required to accelerate the umbilical at the full load shots exceeded the strength of the disconnect safety wire. Repeated failures occurred because the disconnect was not noticeable visually. The cable appeared to pay out correctly. When the data was analyzed in detail and the malfunction discovered, the tests had been completed.

The validity of the data recorded was not affected. Prior experience with determination of sled accelerator from piston pressure agreed within acceptable limits of accuracy. Therefore, the validity of the data is considered to not have been significantly affected by the disconnect.

KAMAN SEAT TEST CONDITION NO. 1

Under this test condition, the seat was oriented 28 degrees above the horizontal, as shown in Figure 14. The sled accelerated approximately 18 inches before the dummy began to move. During this time, the chest armor was forced forward, and at approximately 0.060 second, the chest armor retention strap failed and released the chest armor. Shortly thereafter, the right seat belt load link failed and the shoulder harness strap pulled out of the inertia reel (0.09 and 0.12 seconds,

Figure 23. Posttest View of Kaman Seat - Test Condition No. 1.
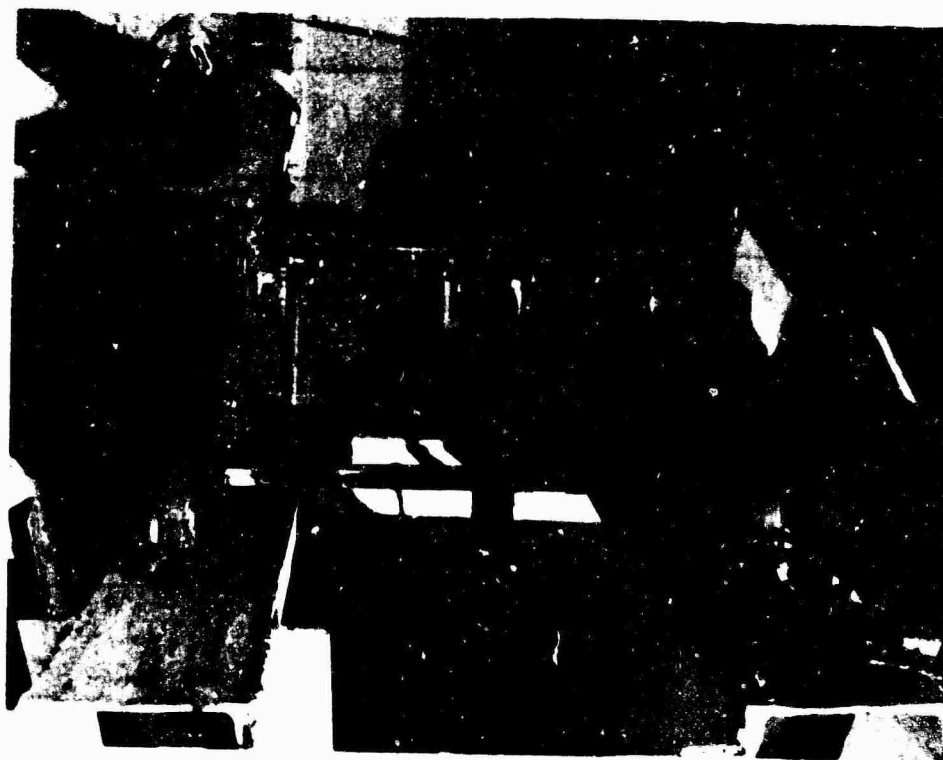
Figure 24. Damage to Front Edge of Seat Pan -
Kaman Seat Test Condition No. 1.

respectively), permitting the dummy to rotate forward and to the left, as shown in the posttest view, Figure 23. Figure 24 shows the buckling of the forward lip of the seat pan, caused during the initial phase of the acceleration pulse.

The sled acceleration, Figure 25I, and the seat accelerations, Figures 25B and 25C, are in general agreement other than for the higher frequency components. Longitudinal and vertical dummy accelerations, Figures 25E and 25F, were affected by a shift in dummy position.

The seat-belt and shoulder-harness loads, Figures 25G, 25H, and 25J, clearly reflect the failure described above. It is believed that the seat would have carried the loads imposed in this test had the load link not failed. The test was not repeated.

KAMAN SEAT TEST CONDITION NO. 2

Because the design lateral load factor for the Kaman seat was only 10.5G, the seat was oriented at 23 degrees from the thrust axis instead of the 28-degree position shown in Figure 14. This was done to reduce the anticipated 23G sled acceleration to 10.5G. During the initial phase of the acceleration, the sled moved approximately 1 foot before the dummy began to move. At approximately 0.03 second, the dummy's head came off. No failures of the seat or restraint system occurred during the test. Figure 26 is a posttest view of the seat and dummy.

The actual test pulse is shown in Figure 27H and averages about 20G. The theoretical seat longitudinal acceleration would be 20. Cos (23 degrees) = 18.3G, and the lateral acceleration 20. Sin (23 degrees) = 7.8G. Figures 27A and 27B give the measured seat longitudinal and lateral values; they indicate approximate agreement with the expected result.

The dummy lateral acceleration, Figure 27D, is similar to that obtained in the test of the Bell seat. The seat belt load, Figure 27E, is considerably lower than that recorded for Bell seat test condition No. 2. It is assumed that the strap-on armor used with the Kaman seat carried an appreciable part of the longitudinal load normally carried by the seat belt. The shoulder harness load, Figures 27F and 27G, at 1280 pounds was of slightly lower value than recorded in Bell seat test condition No. 2, and it was not maintained for as long an interval. The "wrap-around" chest armor of the Kaman seat probably contributed to the difference in the measured values.
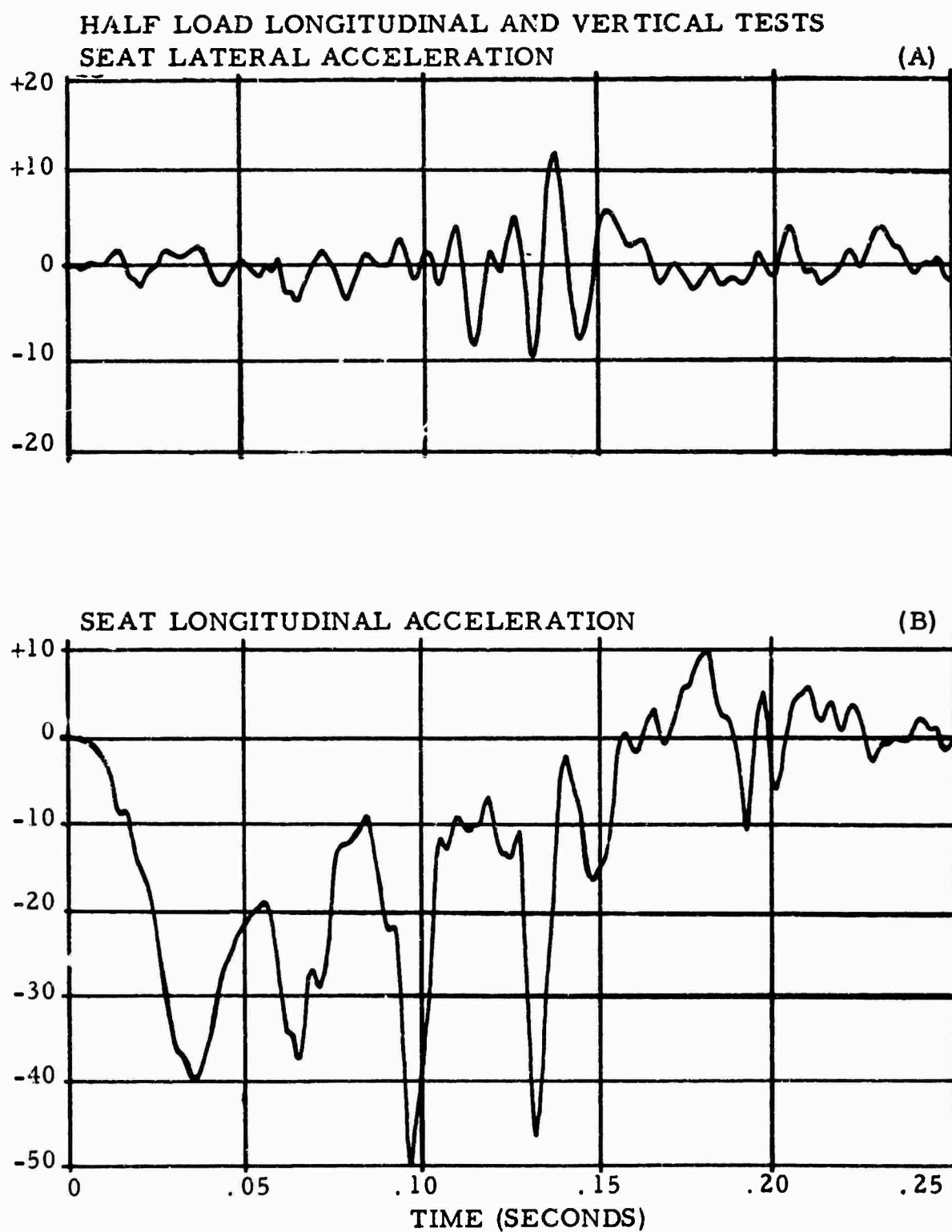
Figure 25. Data Time Histories - Kaman Seat - Test Condition No. 1.

HALF LOAD LONGITUDINAL AND VERTICAL TESTS
SEAT VERTICAL ACCELERATION
(C)

DUMMY LATERAL ACCELERATION
(D)

TIME (SECONDS)
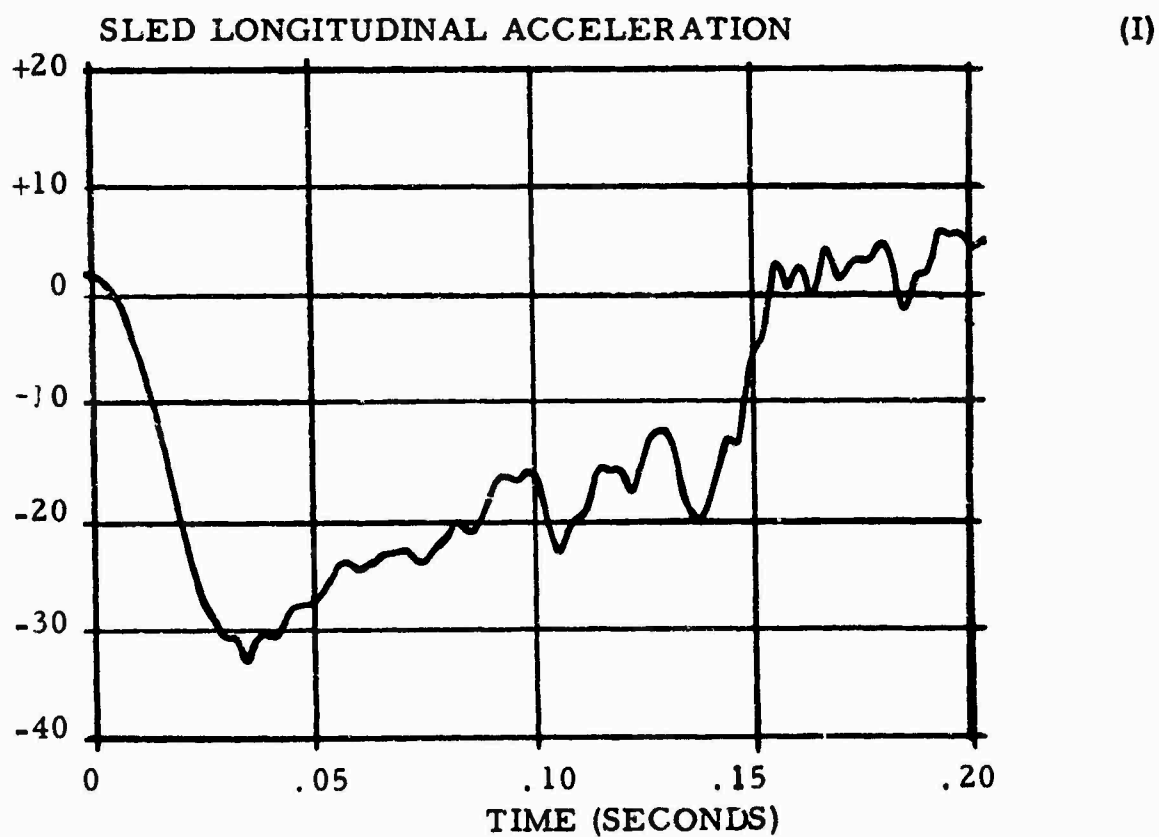
Figure 25 (contd.). Data Time Histories - Kaman Seat -
Test Condition No. 1.

56

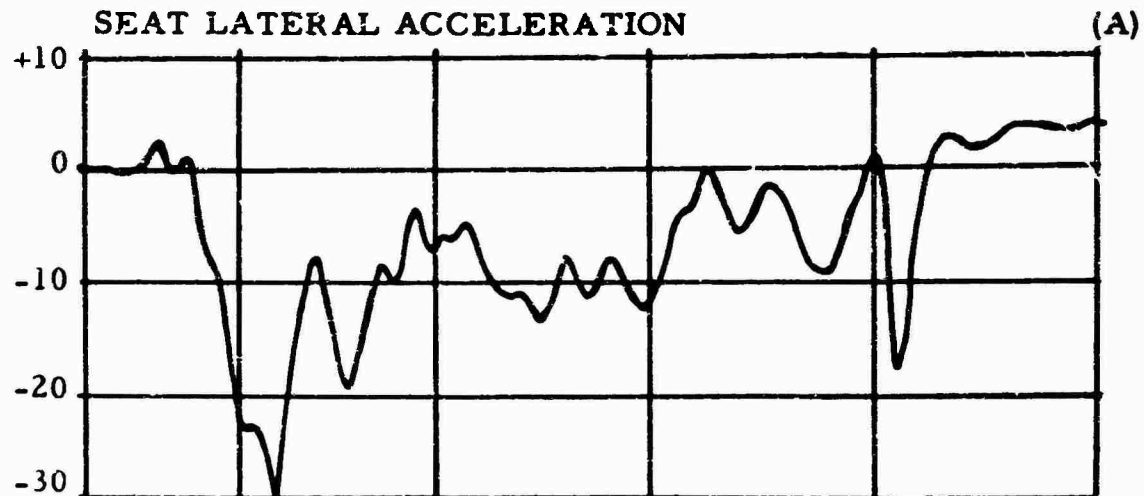# HALF LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY LONGITUDINAL ACCELERATION   (E)

TIME (SECONDS)
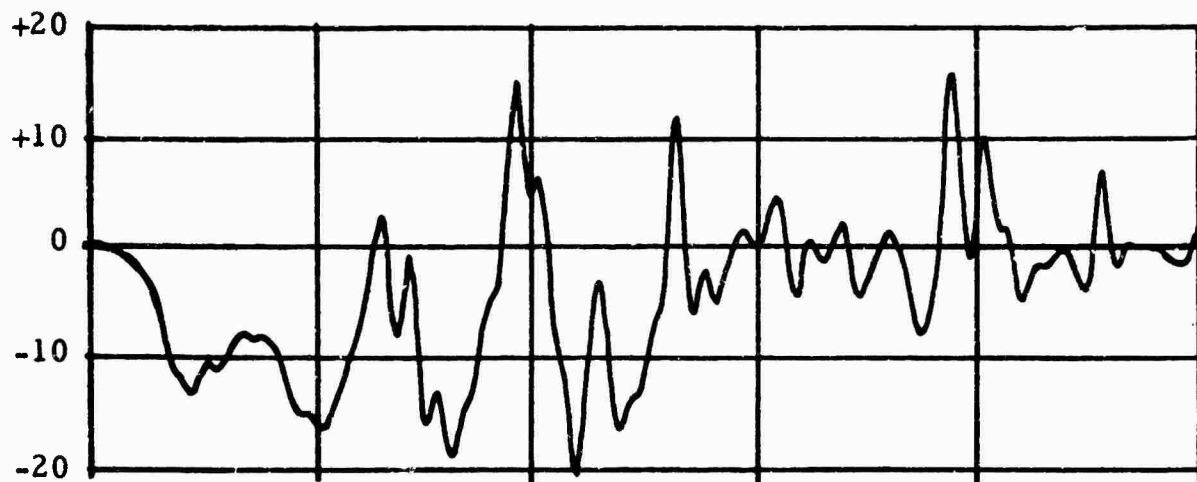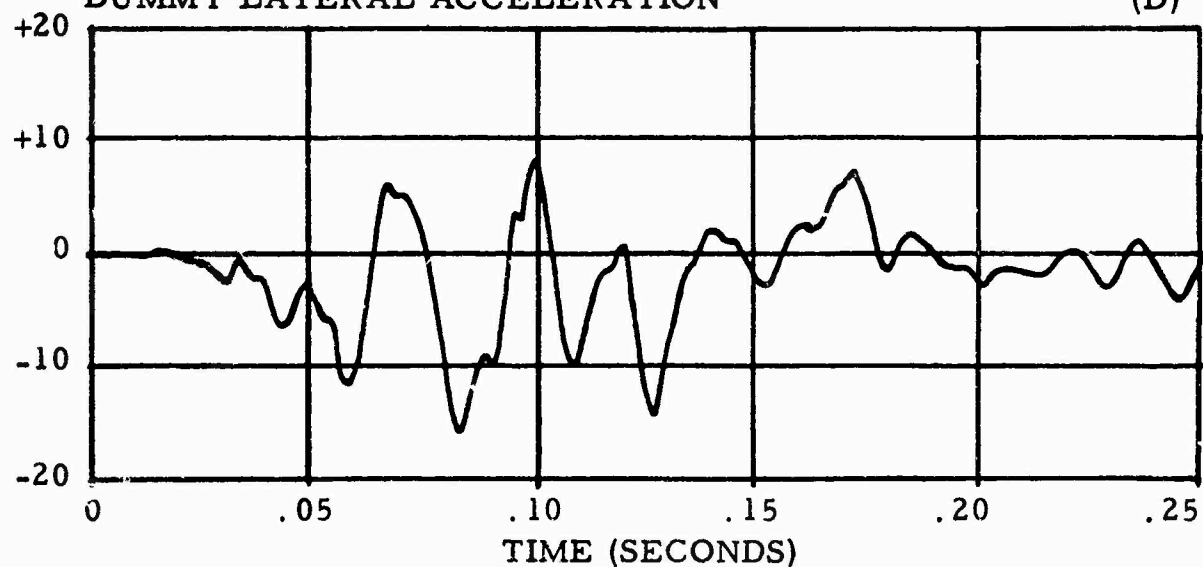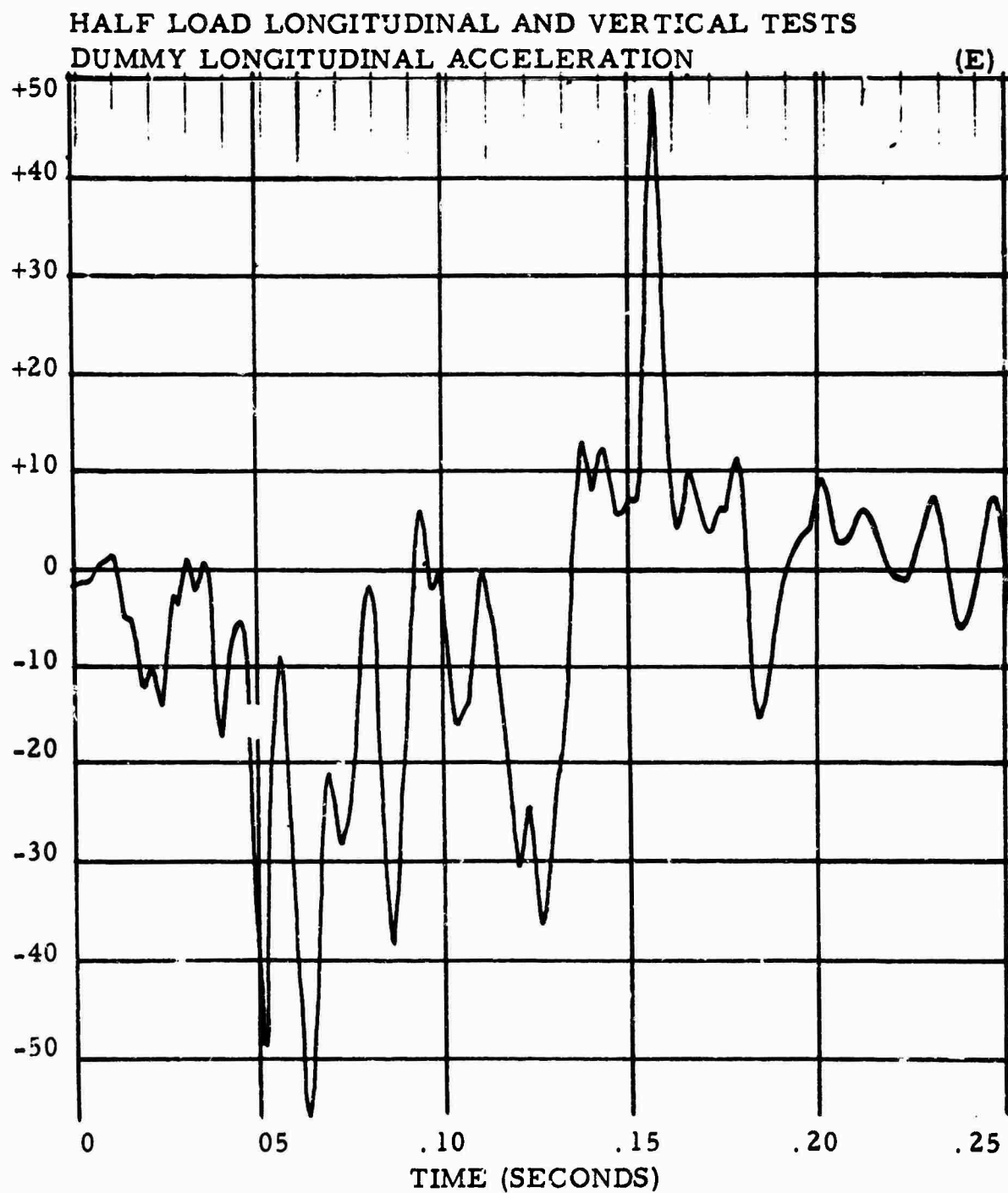
Figure 25 (contd.). Data Time Histories - Kaman Seat - Test Condition No. 1.

HALF LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY VERTICAL ACCELERATION   (F)
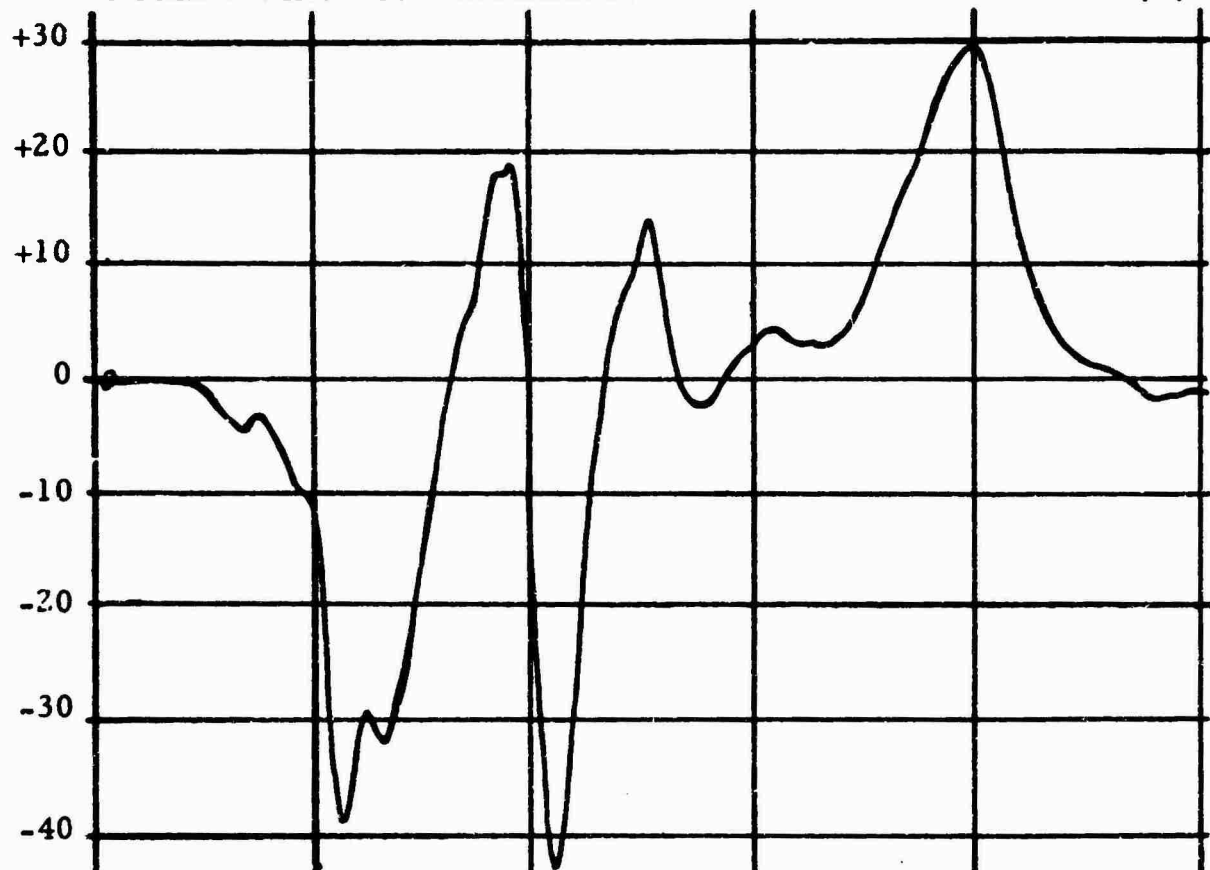
RIGHT HAND SHOULDER HARNESS FORCE   (G)
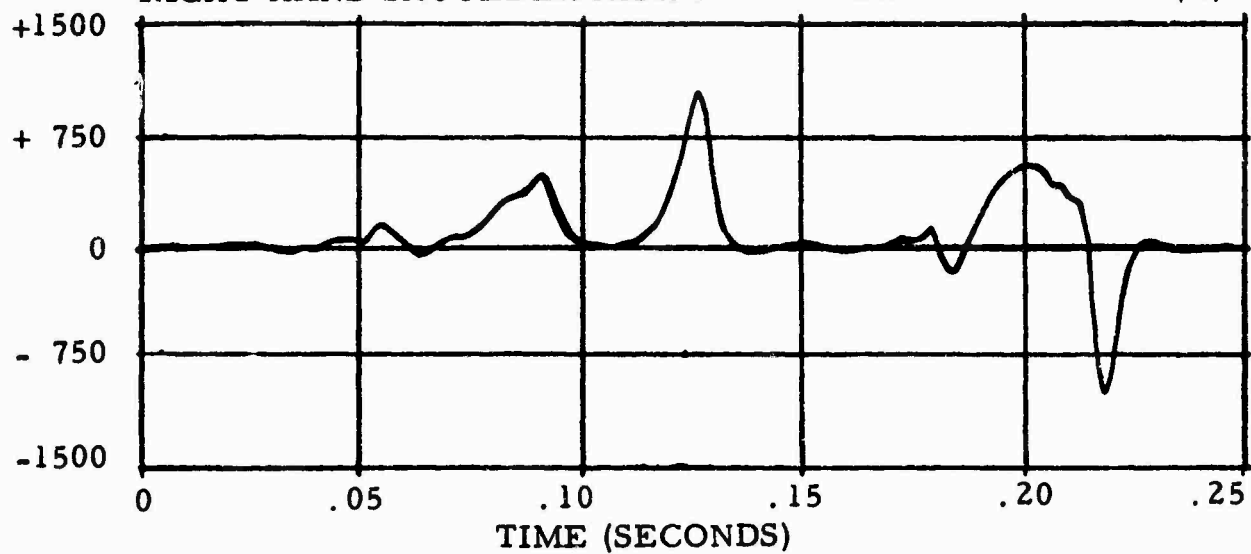
Figure 25 (contd.). Data Time Histories - Kaman Seat -
Test Condition No. 1.
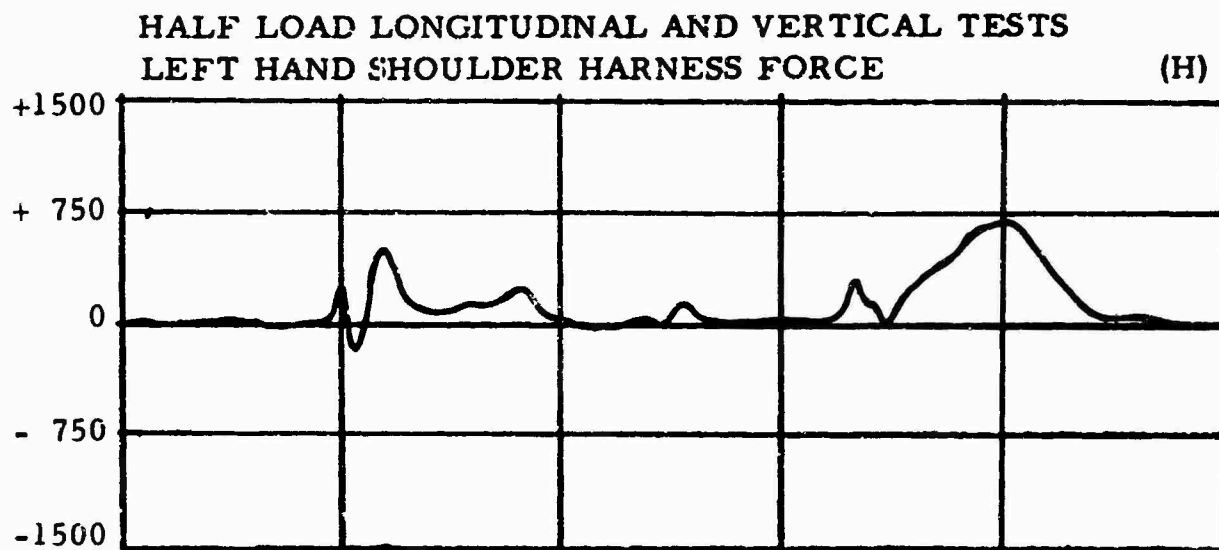
58

HALF LOAD LONGITUDINAL AND VERTICAL TESTS
LEFT HAND SHOULDER HARNESS FORCE (H)

SLED LONGITUDINAL ACCELERATION (I)

TIME (SECONDS)

Figure 25 (contd.). Data Time Histories - Kaman Seat -
Test Condition No. 1.

HALF LOAD LONGITUDINAL AND VERTICAL TESTS
SEAT BELT FORCE
(J)
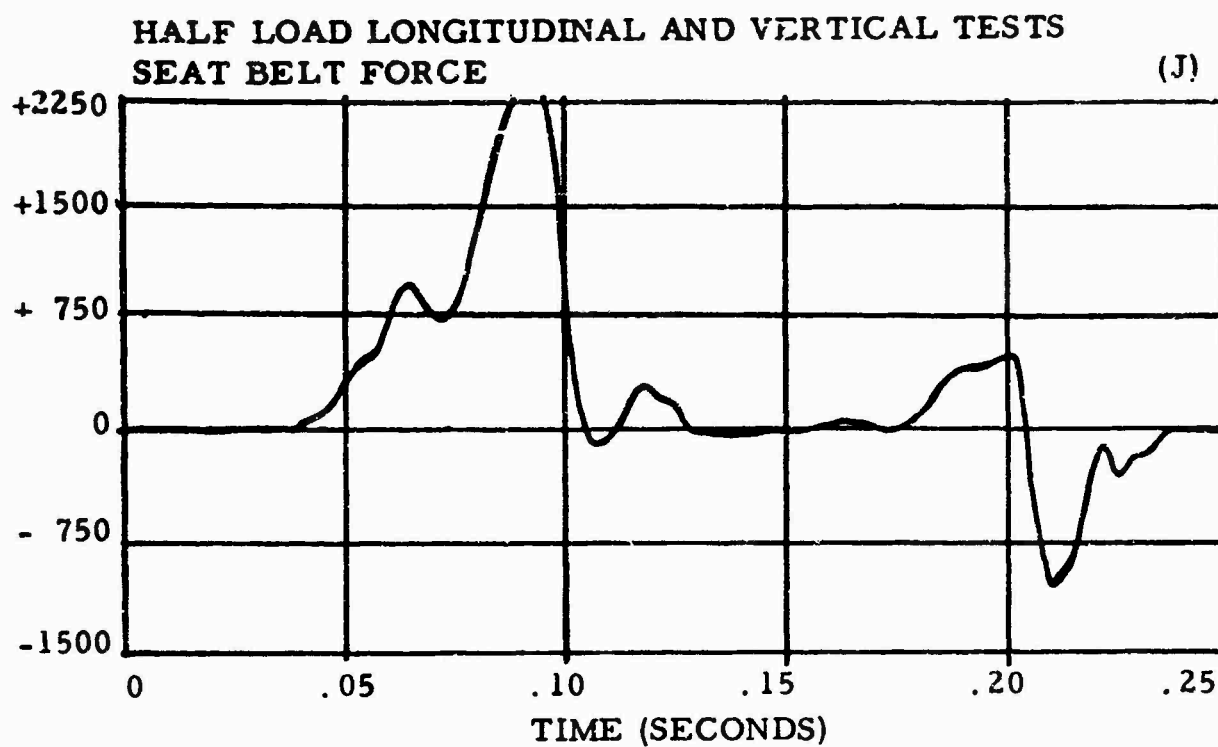
Figure 25 (contd.). Data Time Histories - Kaman Seat -
Test Condition No. 1.

Figure 26. Posttest View of Kaman Seat - Test Condition No. 2.

HALF LOAD LONGITUDINAL AND LATERAL TESTS
SEAT LATERAL ACCELERATION (A)

SEAT LONGITUDINAL ACCELERATION (B)

SEAT VERTICAL ACCELERATION (C)

TIME (SECONDS)
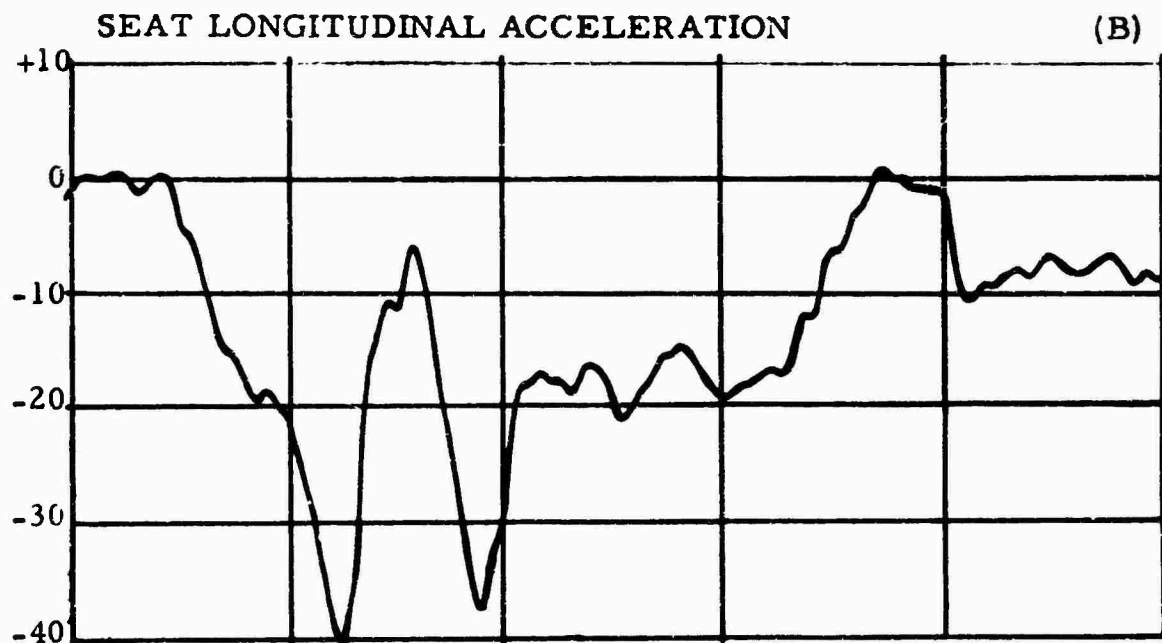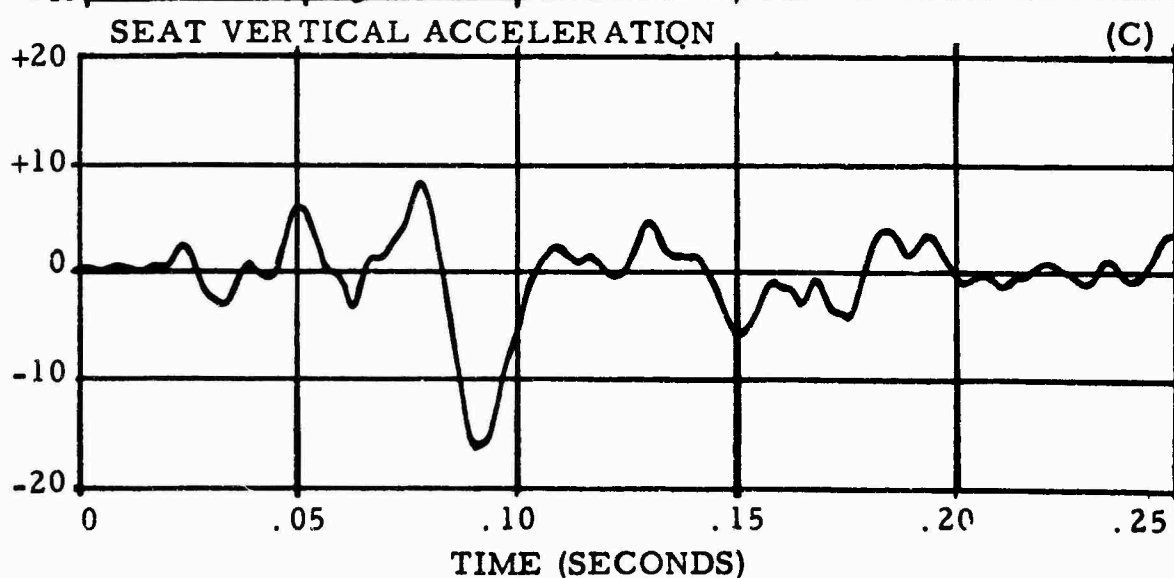
Figure 27. Data Time Histories - Kaman Seat -
Test Condition No. 2.
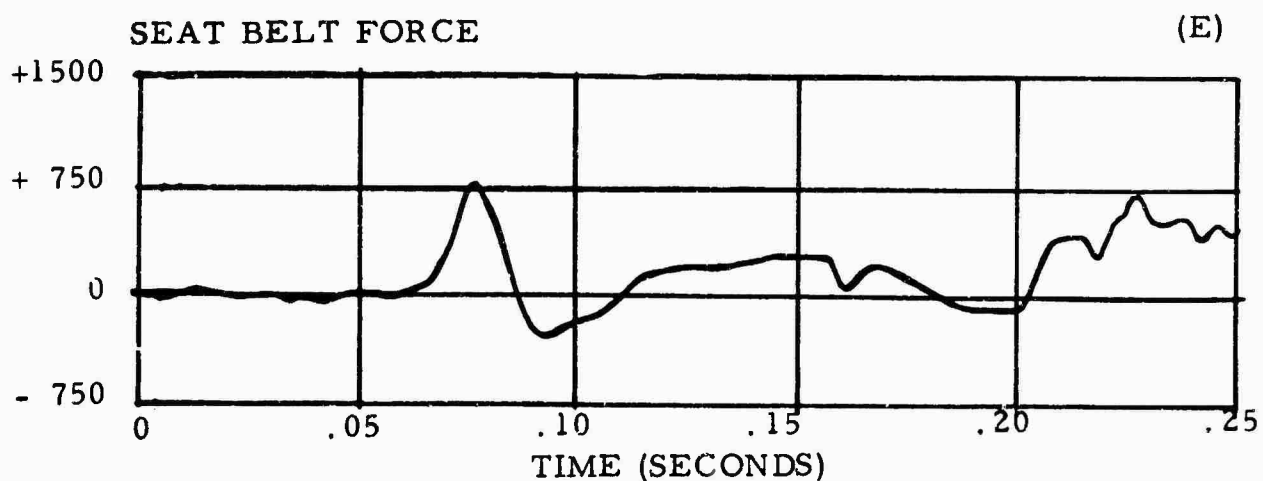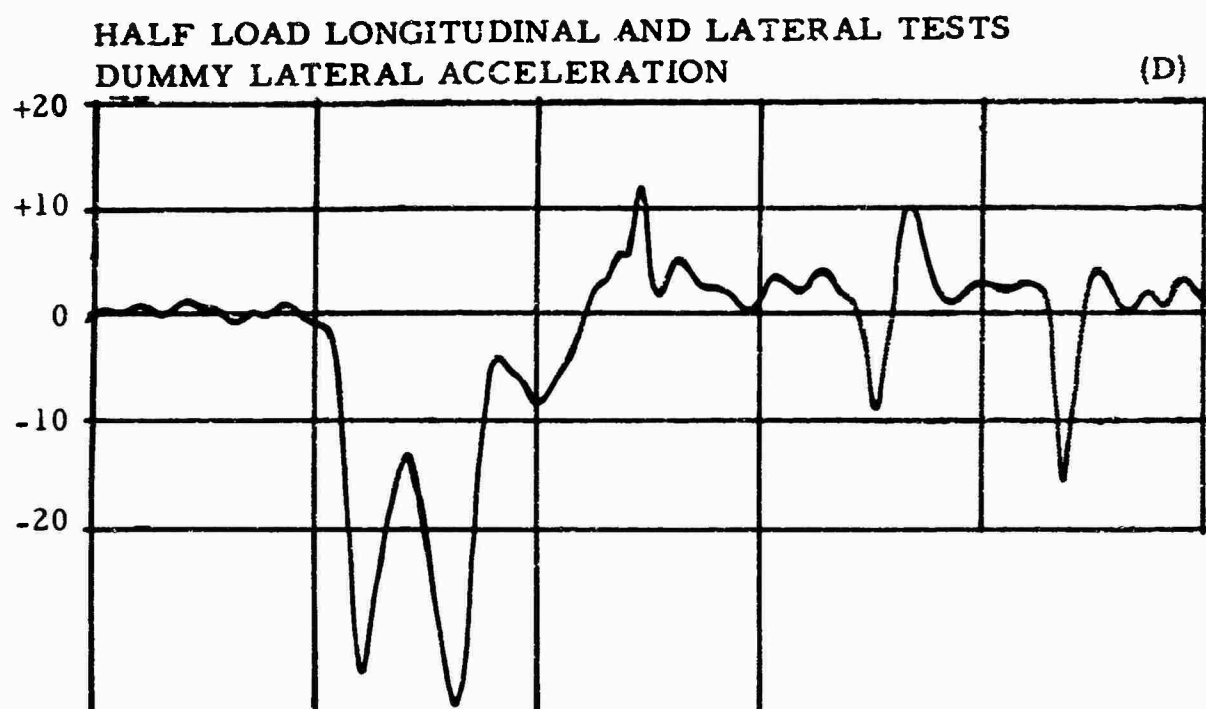
61

HALF LOAD LONGITUDINAL AND LATERAL TESTS
DUMMY LATERAL ACCELERATION

SEAT BELT FORCE

TIME (SECONDS)

Figure 27 (contd.). Data Time Histories - Kaman Seat -
Test Condition No. 2.

HALF LOAD LONGITUDINAL AND LATERAL TESTS
SLED LONGITUDINAL ACCELERATION (H)

TIME (SECONDS)
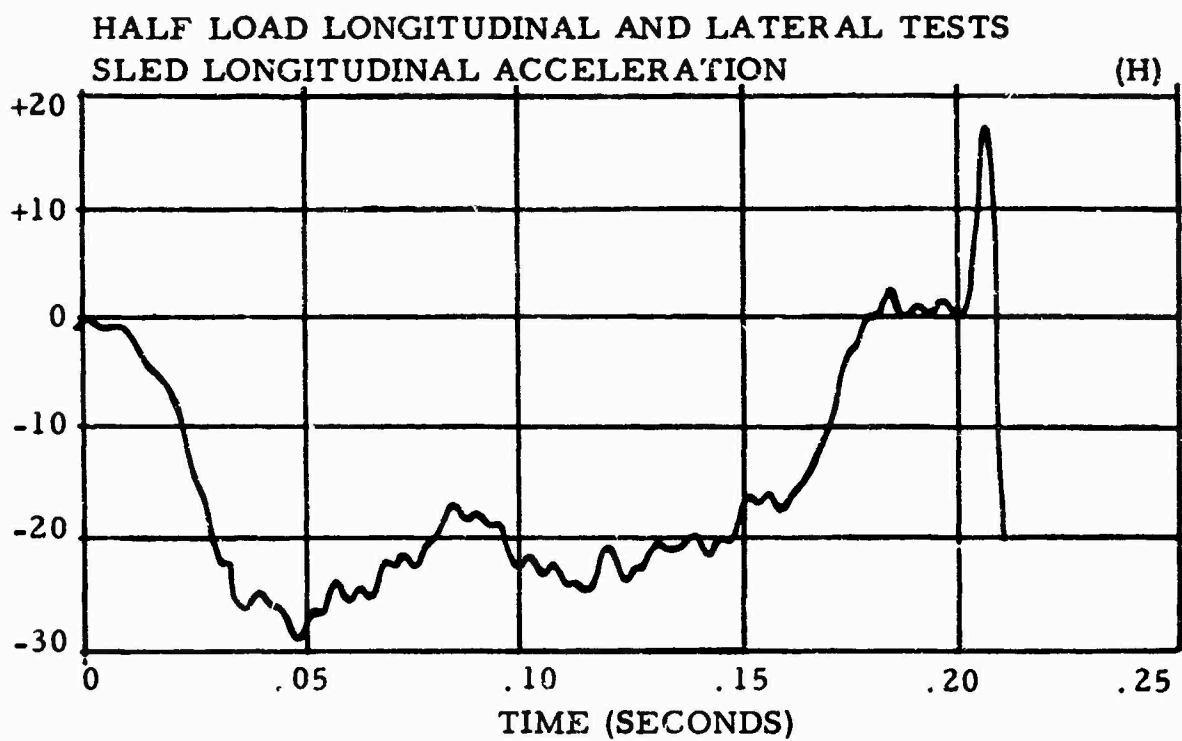
Figure 27 (contd.). Data Time Histories - Kaman Seat - Test Condition No. 2.

Figure 28. Posttest View of Kaman Seat - Test Condition No. 3.

HALF LOAD LONGITUDINAL AND LATERAL TESTS
RIGHT HAND SHOULDER HARNESS FORCE

(F)

LEFT HAND SHOULDER HARNESS FORCE

(G)

TIME (SECONDS)

Figure 27 (contd.). Data Time Histories - Kaman Seat -
Test Condition No. 2.

63
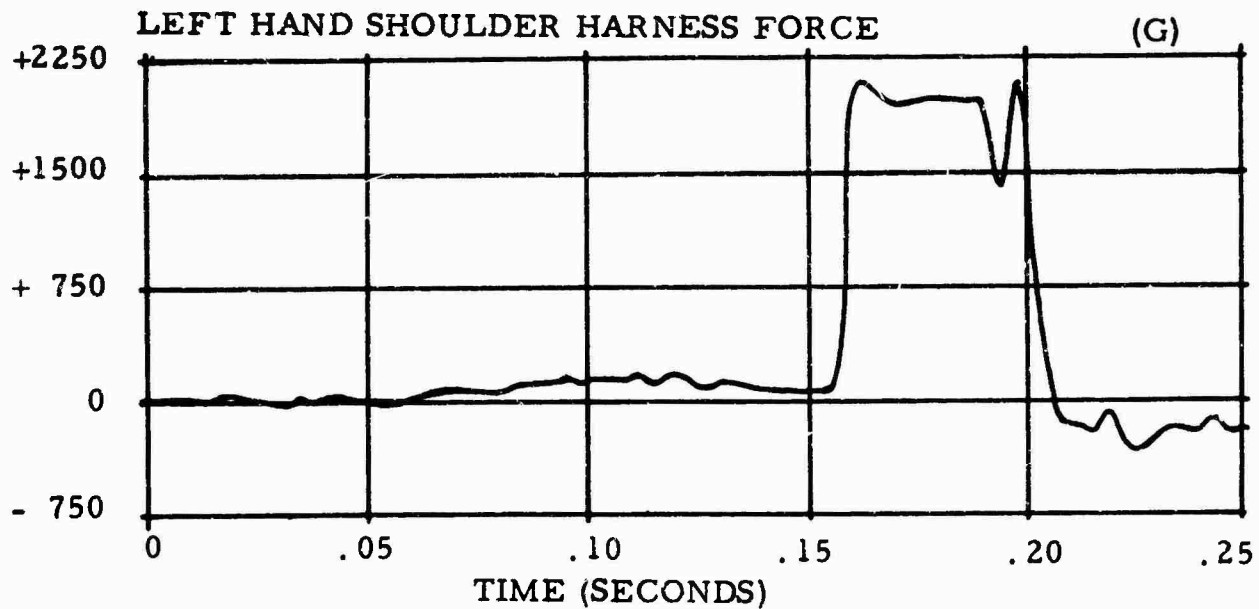
KAMAN SEAT TEST CONDITION NO. 3

This test was a full-load test with the seat mounted 28 degrees upward from the horizontal, as shown in Figure 14. Observation of the high-speed films (see sequence photographs taken from this film, Figure 29) shows that the seat moved upward and forward parallel to the floor mounting rails almost immediately after firing. Seat movement was evident by 0.035 second. The safety cable did not retain the seat on the sled. Visual examination of the seat tracks and seat after the test indicates that the pins that hold the seat in place were not fully extended in the holes, although the locking handle was fully depressed. The only damage to the seat was caused by contact with the ground. Figure 28 is a posttest view of the seat and dummy.

The data presented in Figures 30A through 30G is not significant after about 0.05 millisecond* due to the seat failure and the instrumentation disconnect. The sled acceleration, Figure 30G, peaked at 43G at about 0.06 second. The seat longitudinal acceleration, Figure 30B, reached about 30G by 0.035 second, and also indicated that seat restraint was lost at about this time. The dummy longitudinal acceleration, Figure 30E, reached 60G by 0.04 second and would probably have gone to 80+G if no failure had occurred.

As the seat moved upward and forward along the inclined floor mounting rail (28 degrees attitude), the vertical energy absorber continued to function, and about 5 inches of vertical travel was realized. This downward motion of the seat pan can be seen in the high-speed film, even though it is not apparent in the sequence photographs, Figure 29.

The energy absorber in the Kaman seat was the only one which functioned completely during the series of tests described in this report. Because of the lag between the dummy reaction and the sled input acceleration pulse, the dummy had gone through about 1/3 of the actual change in velocity at the time of instrument disconnect. During this time, the energy absorber had already functioned through its full stroke. Since the absorber was limiting the load during this time, it is reasonable to assume that the vertical acceleration level reached a level far above the 20+G's shown on the Data Time History.

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* Other than the sled acceleration curve, Figure 30G.
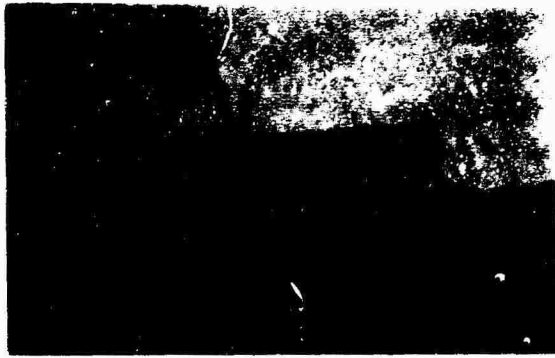
t = 0.0 sec.; first motion

t = 0.033 sec.; sled movement, 3 ft. (seat tiedown has failed)

t = 0.051 sec.; sled movement, 5 ft.

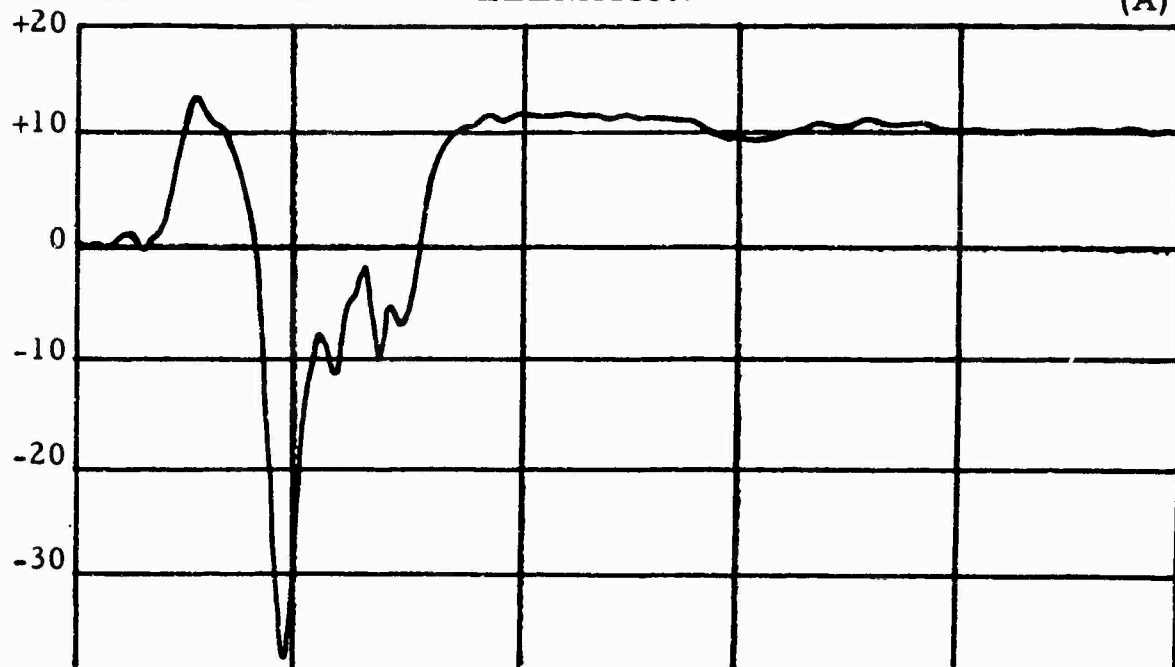t = 0.061 sec.; sled movement, 6 ft. (instrumentation is disconnected)
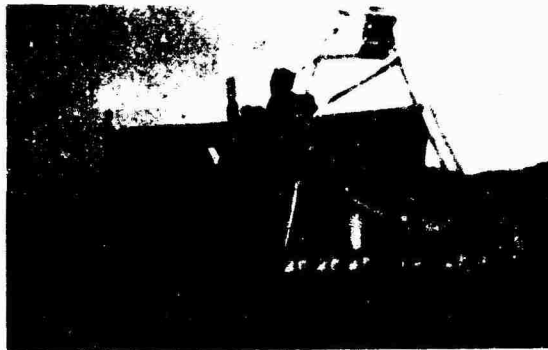
t = 0.071 sec.; sled movement, 7 ft.

Figure 29.   Sequence Photographs of Kaman Seat - Test Condition No. 3.

FULL LOAD LONGITUDINAL AND VERTICAL TESTS
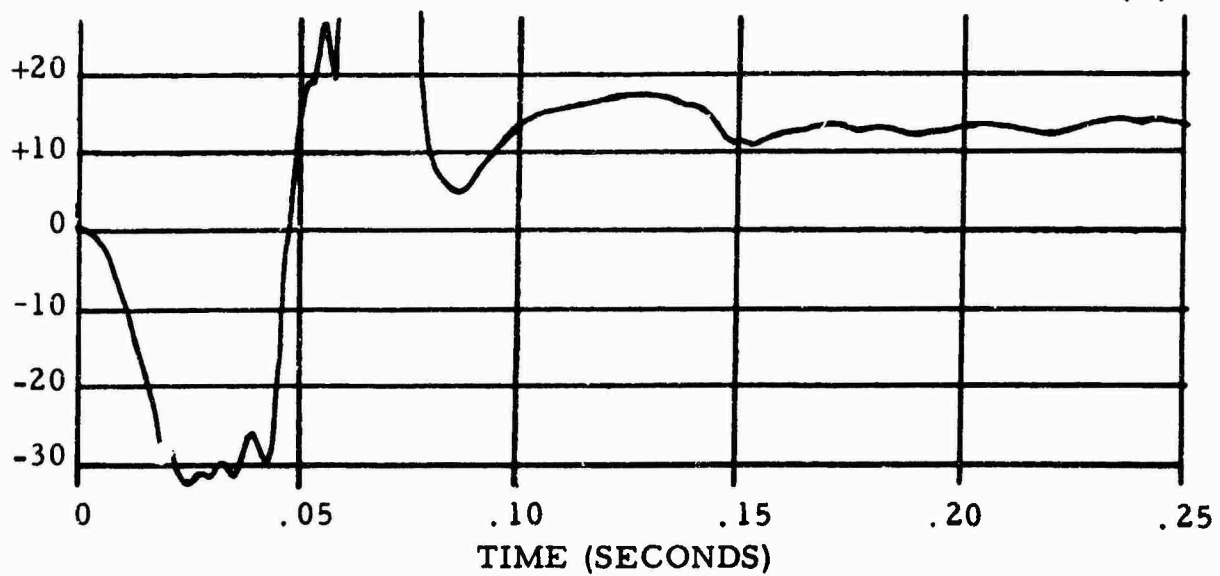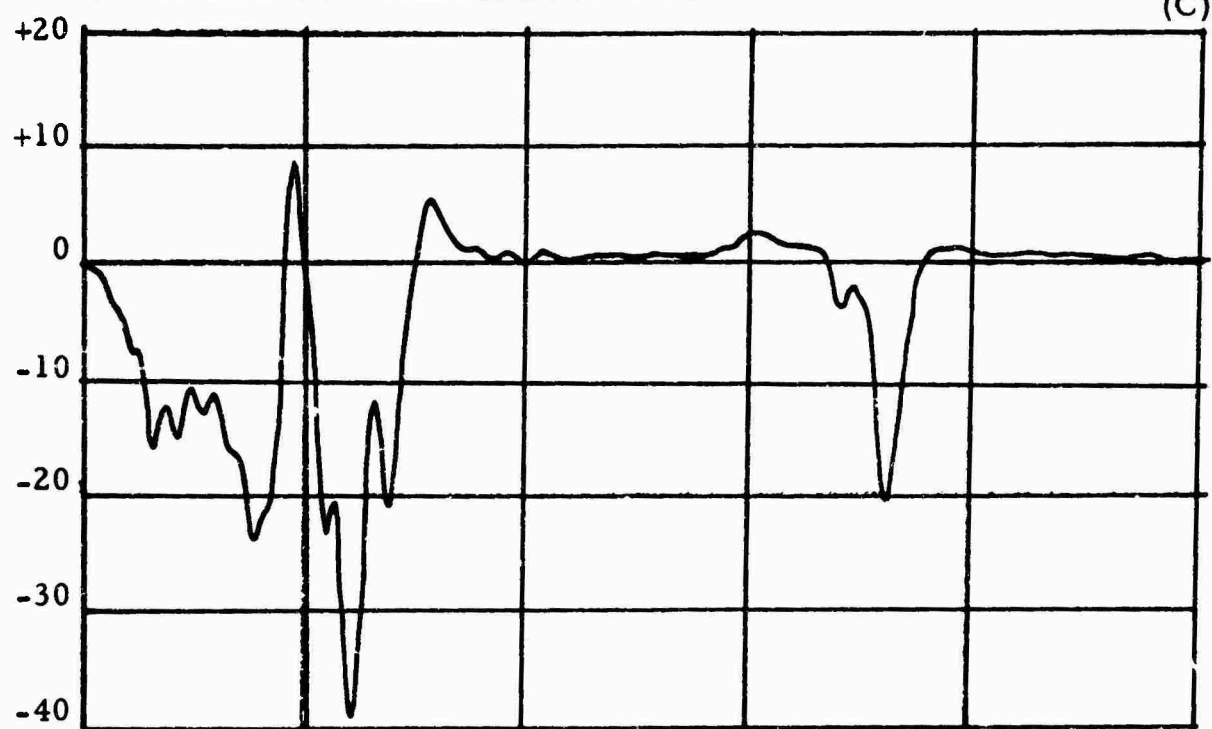## SEAT LATERAL ACCELERATION

(A)

SEAT LONGITUDINAL ACCELERATION

(B)

TIME (SECONDS)

Figure 30. Data Time Histories - Kaman Seat -
Test Condition No. 3.

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FULL LOAD LONGITUDINAL AND VERTICAL TESTS
SEAT VERTICAL ACCELERATION

(C)

DUMMY LATERAL ACCELERATION

(D)

TIME (SECONDS)

Figure 30 (contd.). Data Time Histories - Kaman Seat - Test Condition No. 3.

FULL LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY LONGITUDINAL ACCELERATION

(E)

DUMMY VERTICAL ACCELERATION

(F)

TIME (SECONDS)
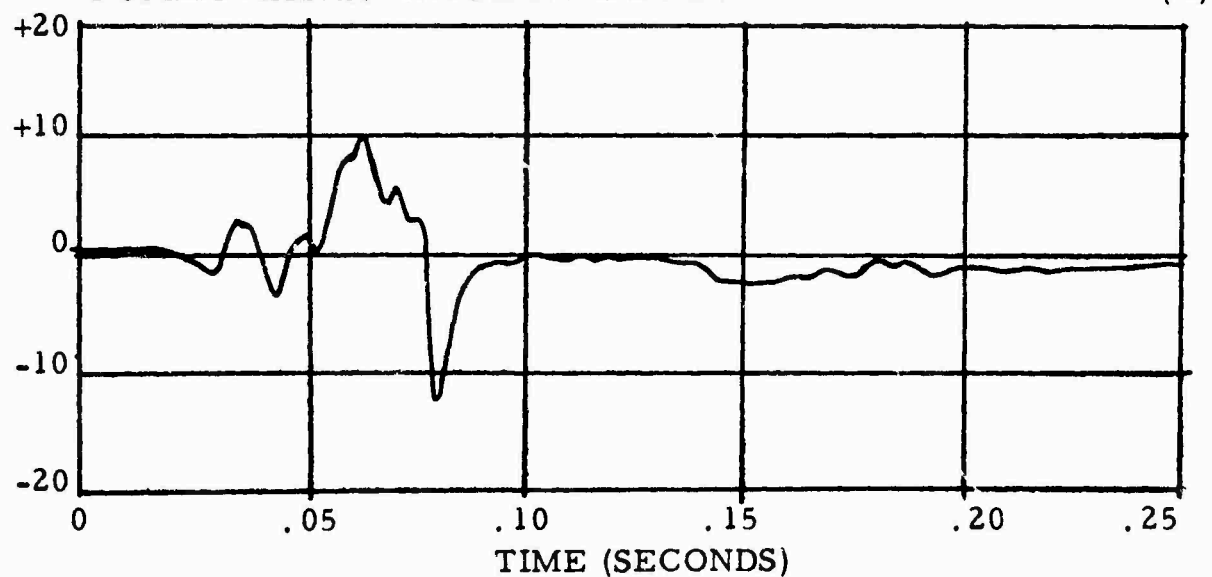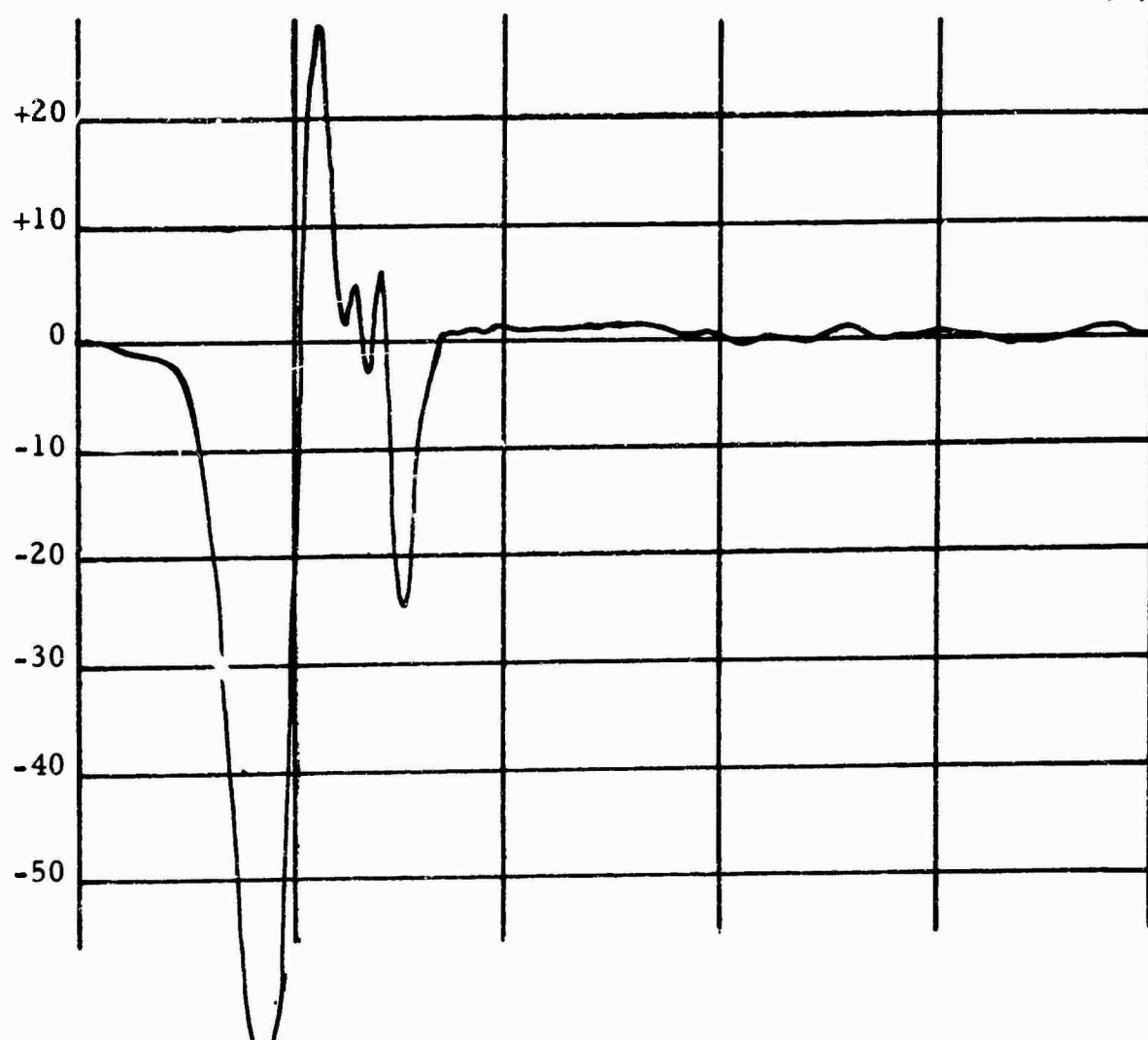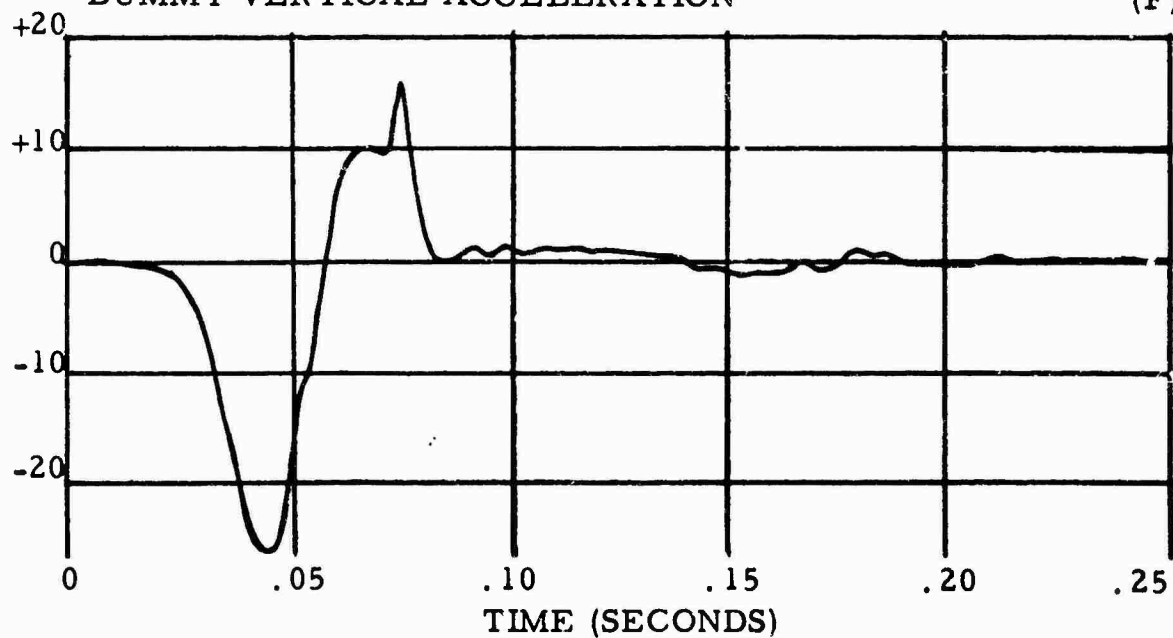
Figure 30 (contd.). Data Time Histories - Kaman Seat -
Test Condition No. 3.

FULL LOAD LONGITUDINAL AND VERTICAL TESTS
SLED LONGITUDINAL ACCELERATION
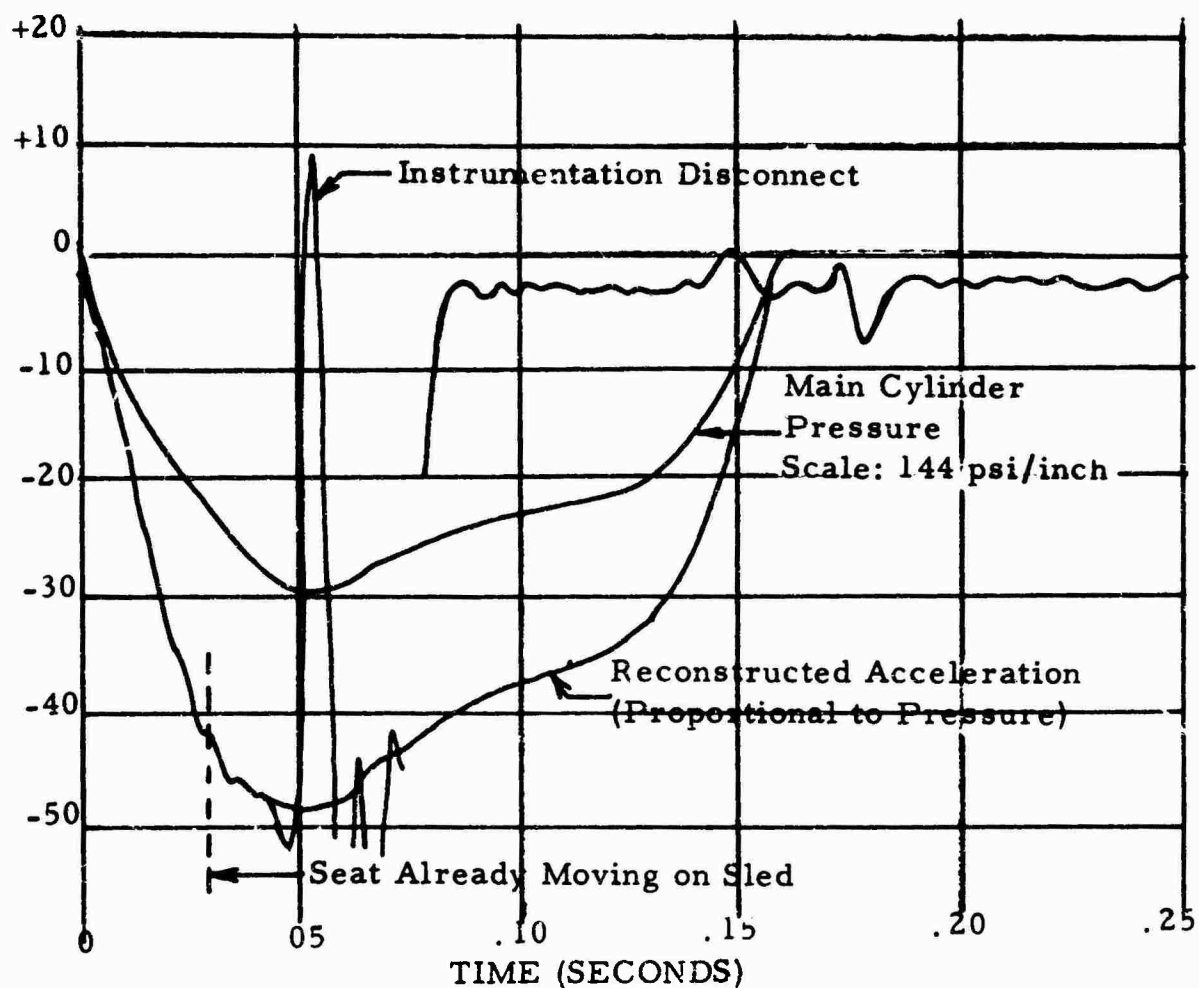
(G)

Figure 30 (contd.).   Data Time Histories - Kaman Seat -
Test Condition No. 3.

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SIKORSKY SEAT TEST CONDITION NO. 1

For this test, the seat was oriented 28 degrees upward from horizontal to provide for both longitudinal and vertical loads, as shown in Figure 14. During the initial phase of the acceleration, the sled moved approximately 15 inches (0.038 second) before the dummy began to move. The hinged part of the chest armor came off at approximately 0.055 second, and this was the only failure experienced. Figure 31 is a posttest view of the dummy and seat.

The sled acceleration on this test approached the desired trapezoidal shape and is shown in Figure 34G. The seat longitudinal and vertical accelerations, as recorded in Figures 34B and 34C, are in excellent agreement with the sled accelerations.

The dummy pelvic vertical acceleration, Figure 34E, shows a severe dynamic overshoot. This dynamic response of the pelvic region of the dummy to the input pulse is dependent upon the spring rate of the dummy itself as well as upon the spring rate and depth of the seat cushion. The cushion used in the Sikorsky seat possibly contributed to the high initial peak shown in Figure 34E. The cushion consisted of 1.5 inches of soft flexible foam (1.4 pound per cubic foot) and 1 inch of a semirigid foam (1.36 pound per cubic foot). A second test (conducted on the Sikorsky seat in the same 28-degree position) gave an almost identical response (figures not included in this report). The Kaman seat, which used 3 inches of soft, flexible foam, gave a similar response (Figure 25). The Bell seat, which employed a contoured seat of much stiffer foam (3-inch average thickness), gave less dynamic overshoot (Figure 17). The right-hand and left-hand seat belt loads are shown in Figures 34H and 34I and are almost identical, as anticipated. The maximum load is about 2300 pounds each side. The shoulder harness load, Figure 34F, reached a maximum value of 1650 pounds. The shoulder harness and seat belt loads are maintained from about 0.030 second to about 0.20 second. This agrees well with the results obtained on the Bell test condition No. 1.

SIKORSKY SEAT TEST CONDITION NO. 2

The Sikorsky seat test condition No. 2 resulted in a failure of the load link attachments in the seat belt at approximately 0.045 second; this resulted in the dummy's being ejected from the seat. Although the data are presented herein in Figure 35, it is not considered significant because of the seat belt failure and is not further discussed. Since a full-load longitudinal-lateral test was successfully made with this seat (condition No. 4), it was not felt necessary to repeat this half-load test.

Figure 31. Posttest View of Sikorsky Seat - Test Condition No. 1.

Figure 32. Posttest View of Sikorsky Seat - Test Condition No. 3.

SIKORSKY SEAT TEST CONDITION NO. 3

This was a full-load test with the seat mounted 28 degrees upward from the horizontal. There were no seat or restraint system failures. The only damage observed was in the slight bow in the rear backs of the seat and in the dummy's head coming off. A posttest view of the seat and headless dummy is shown in Figure 32, and a series of sequence photographs is shown in Figure 33. The effectiveness of the special Sikorsky restraint harness is evident in this series of photographs.

Excellent records were obtained in this test, even though a premature instrumentation disconnect occurred approximately 0.050 second prior to completion of the main pulse. A study of the records, Figures 36A through 36J, shows that all data channels probably reached their peak readings prior to disconnect and that a simple extrapolation of the curves will allow close approximation of the results obtained during this 0.050 period. The sled longitudinal acceleration and main cylinder pressure curves are given in Figure 36G. The maximum acceleration was 38G, occurring at t = 0.050 second. The seat longitudinal acceleration, given by Figure 36B, averaged approximately 32G in the region of peak sled acceleration. This value of 32G corresponds closely to the computed value of 38 x Cos 28 degrees = 33.5G, which theoretically would occur for an infinitely rigidly mounted seat. The seat vertical acceleration, Figure 36C, averages about 16G during the interval of maximum sled acceleration. This value agrees with a computed value of 38 x Sin 28 degrees = 18G.

Figures 36A and 36D show no appreciable lateral seat or pelvic response to the longitudinal-lateral input.

The dummy longitudinal acceleration, Figure 36F, is characteristic of that recorded in some of the Bell and Vertol half-load tests. The dummy vertical acceleration, Figure 36E, is also similar to the records obtained previously in the Bell and Sikorsky half-load tests. Both the vertical and longitudinal accelerations of Figure 36E and Figure 36F show short-period, high-duration peaks, if the high-frequency components are included in the record. Caution should be exercised in relating these high-frequency components to the anticipated loads on a human seat occupant.

The seat belt loads, Figure 36I and Figure 36J, are similar in shape to those recorded in the half-load tests, as shown in Figures 34H and 34I. The magnitude of the loads for the full-load tests is on an average about double that for the half-load test.

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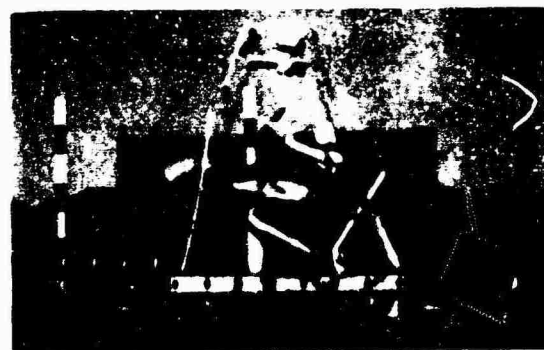t = 0.0 sec.; first motion

t = 0.036 sec.; sled movement, 1 ft.
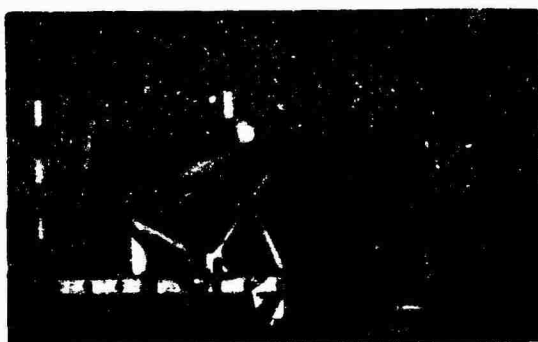
t = 0.056 sec.; sled movement, 2 ft.
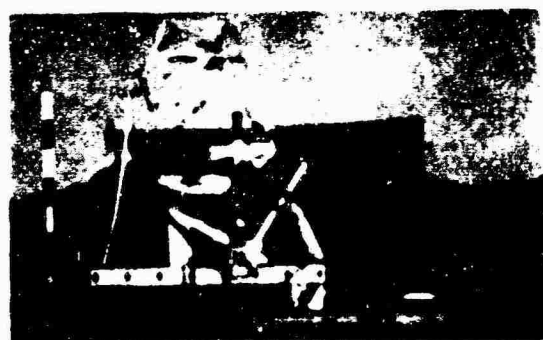
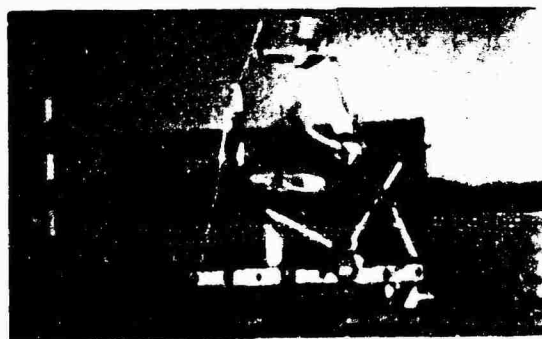t = 0.072 sec.; sled movement, 3 ft.
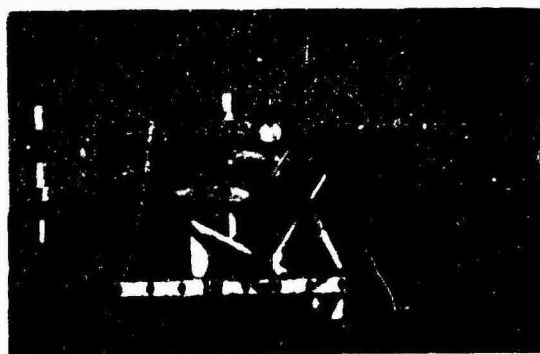
t = 0.087 sec.; sled movement, 4 ft.

t = 0.101 sec.; sled movement, 5 ft.
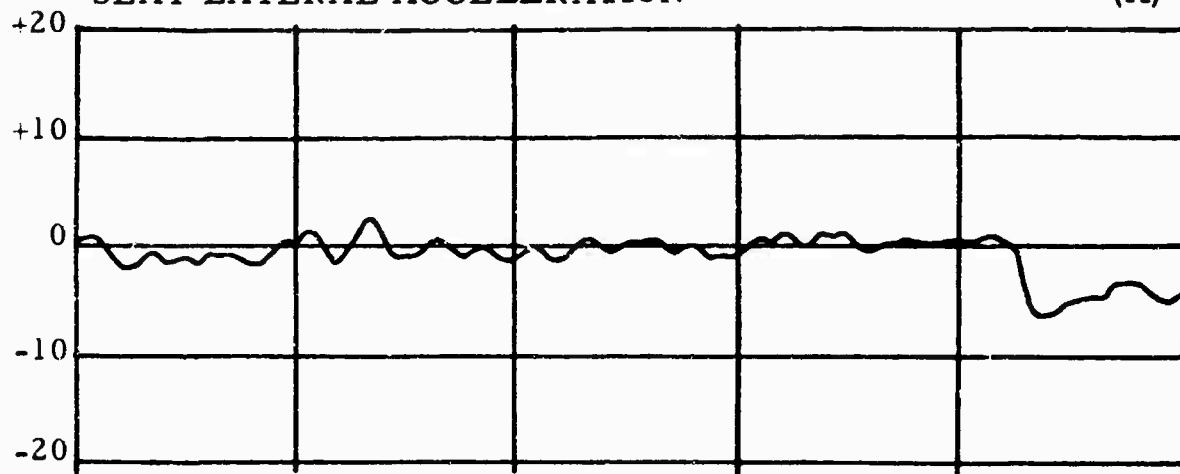(instrumentation has disconnected)

t = 0.111 sec.; sled movement, 6 ft.

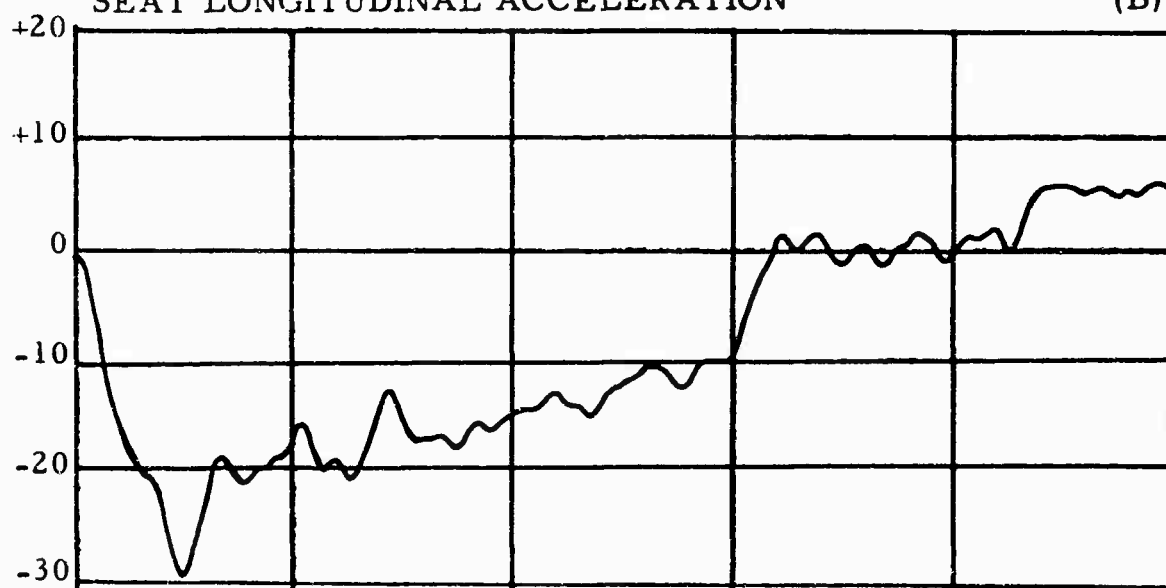Figure 33. Sequence Photographs of Sikorsky Seat - Test Condition No. 3.

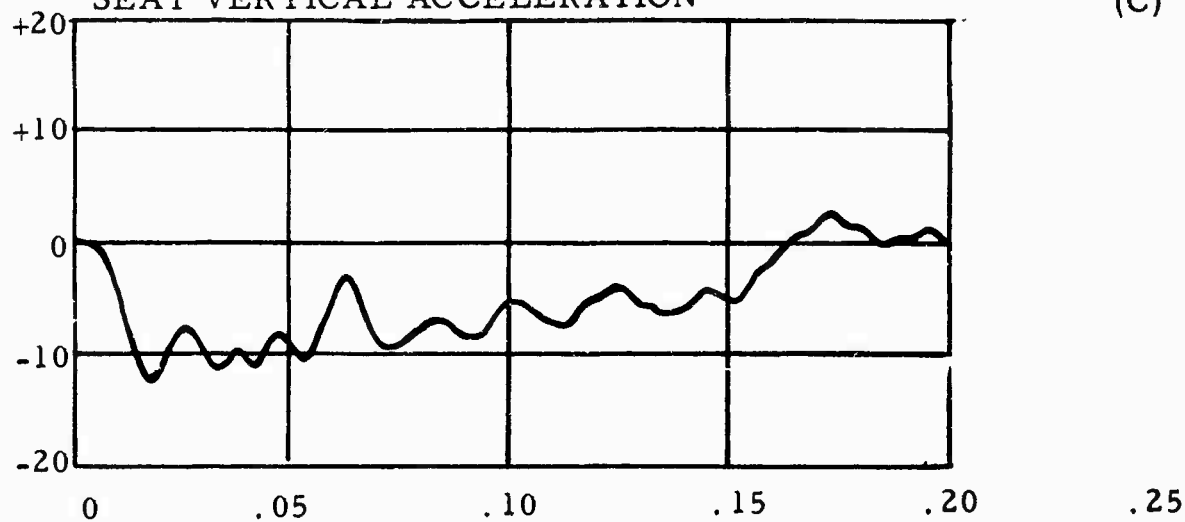# HALF LOAD LONGITUDINAL AND VERTICAL TESTS

SEAT LATERAL ACCELERATION (A)

SEAT LONGITUDINAL ACCELERATION (B)

SEAT VERTICAL ACCELERATION (C)
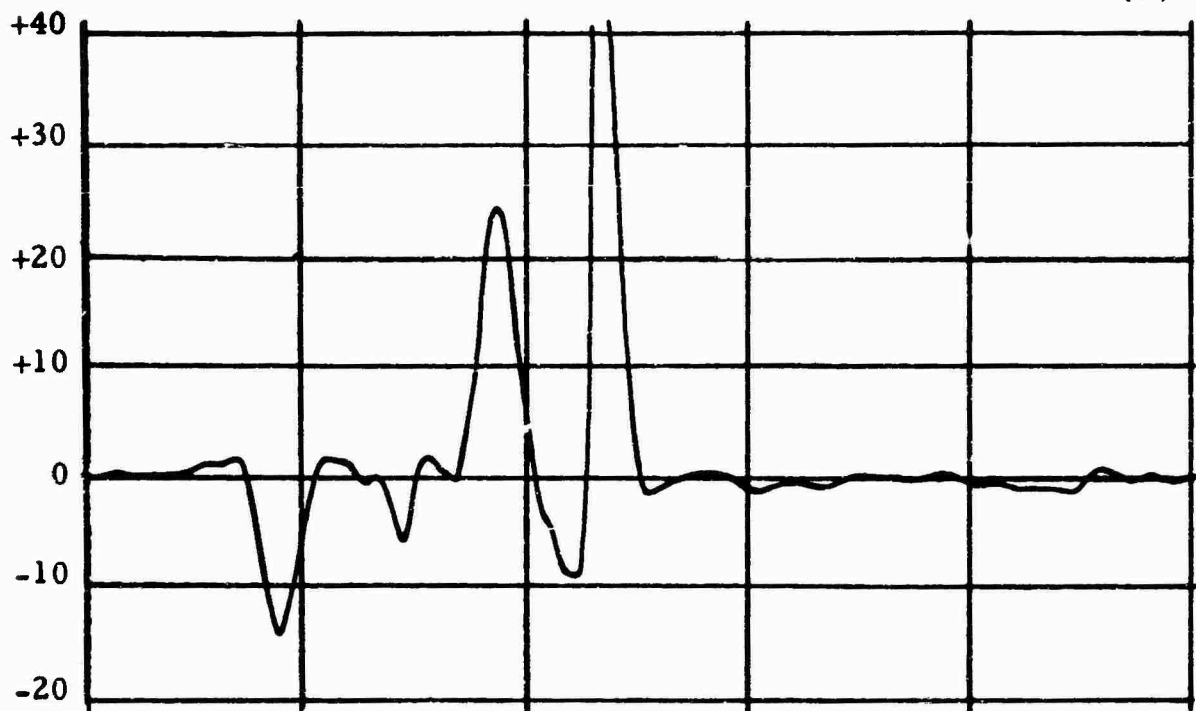
TIME (SECONDS)
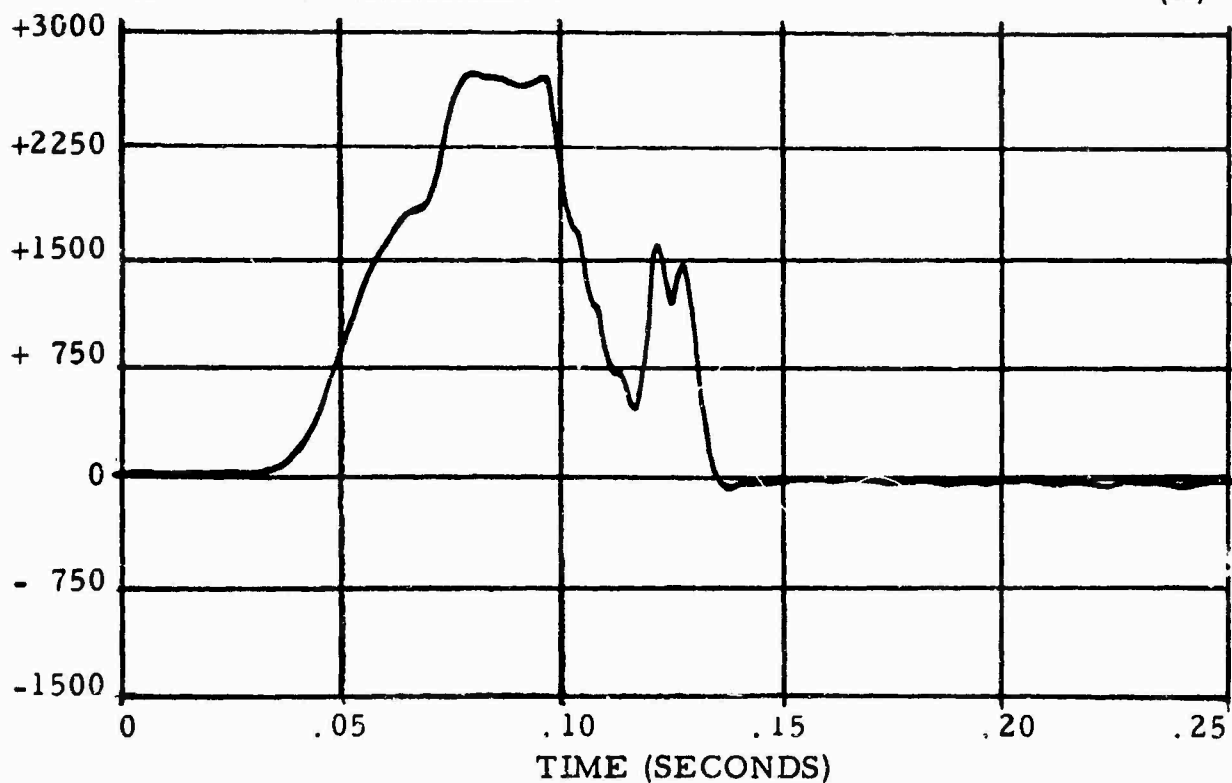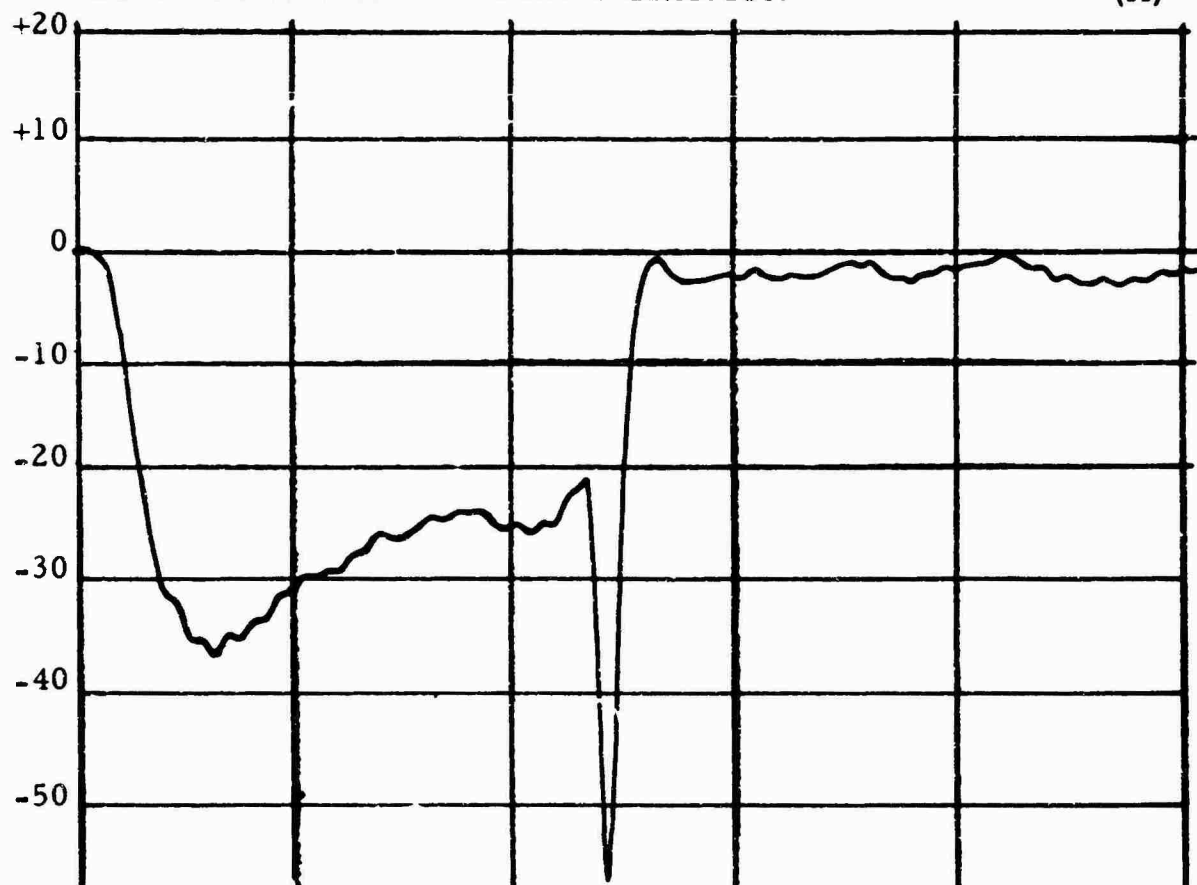
Figure 34. Data Time Histories - Sikorsky Seat -
Test Condition No. 1.
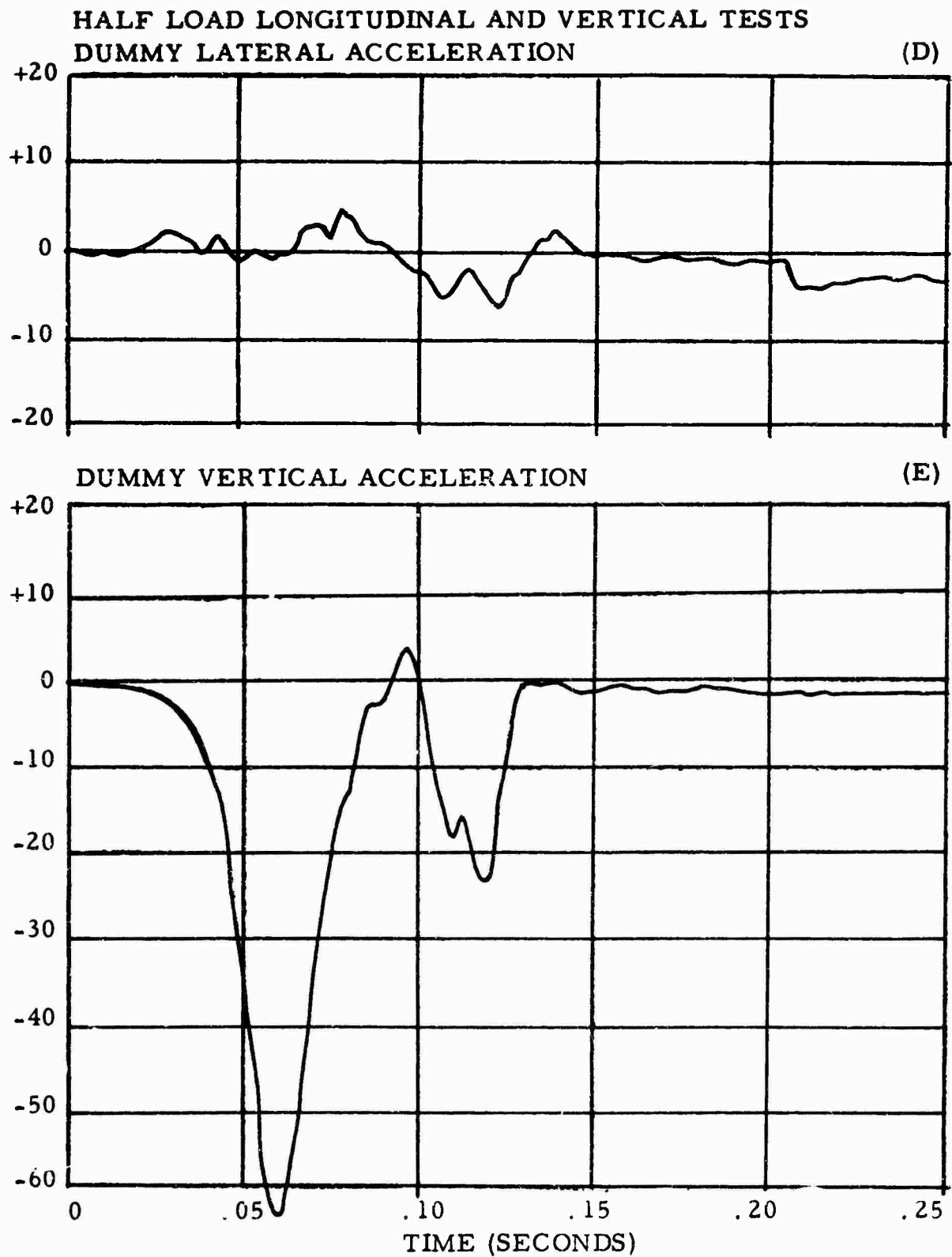
Figure 34 (contd.). Data Time Histories - Sikorsky Seat -
Test Condition No. 1.
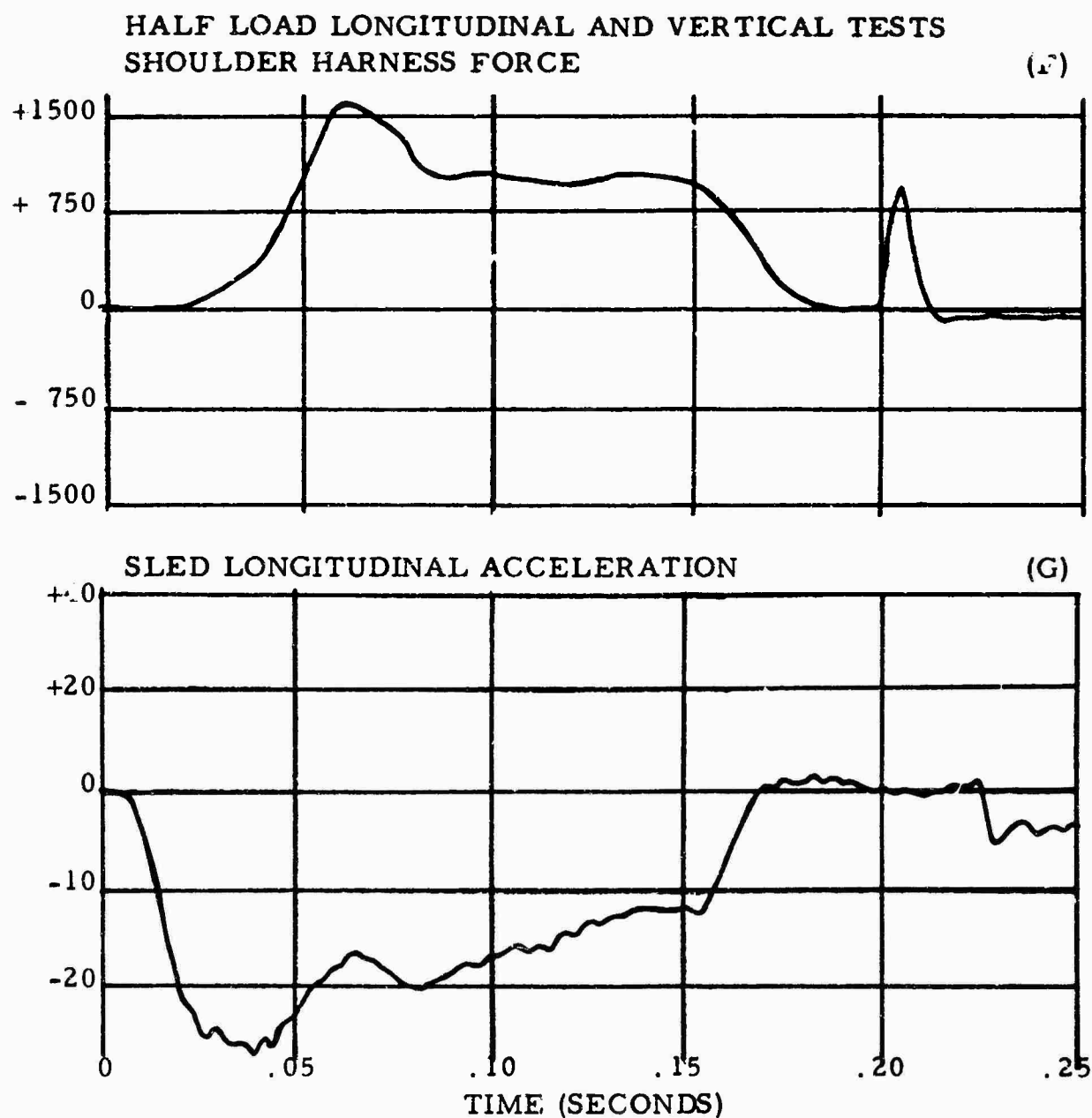
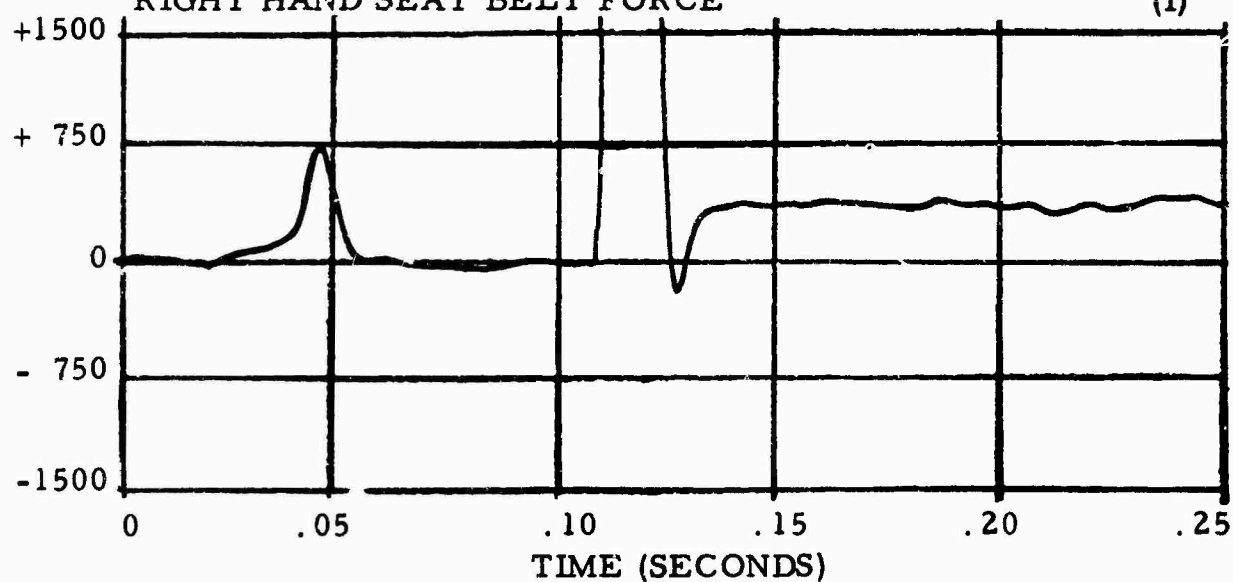# HALF LOAD LONGITUDINAL AND VERTICAL TESTS
SHOULDER HARNESS FORCE
(

Figure 34 (contd.). Data Time Histories - Sikorsky Seat - Test Condition No. 1.

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HALF LOAD LONGITUDINAL AND VERTICAL TESTS
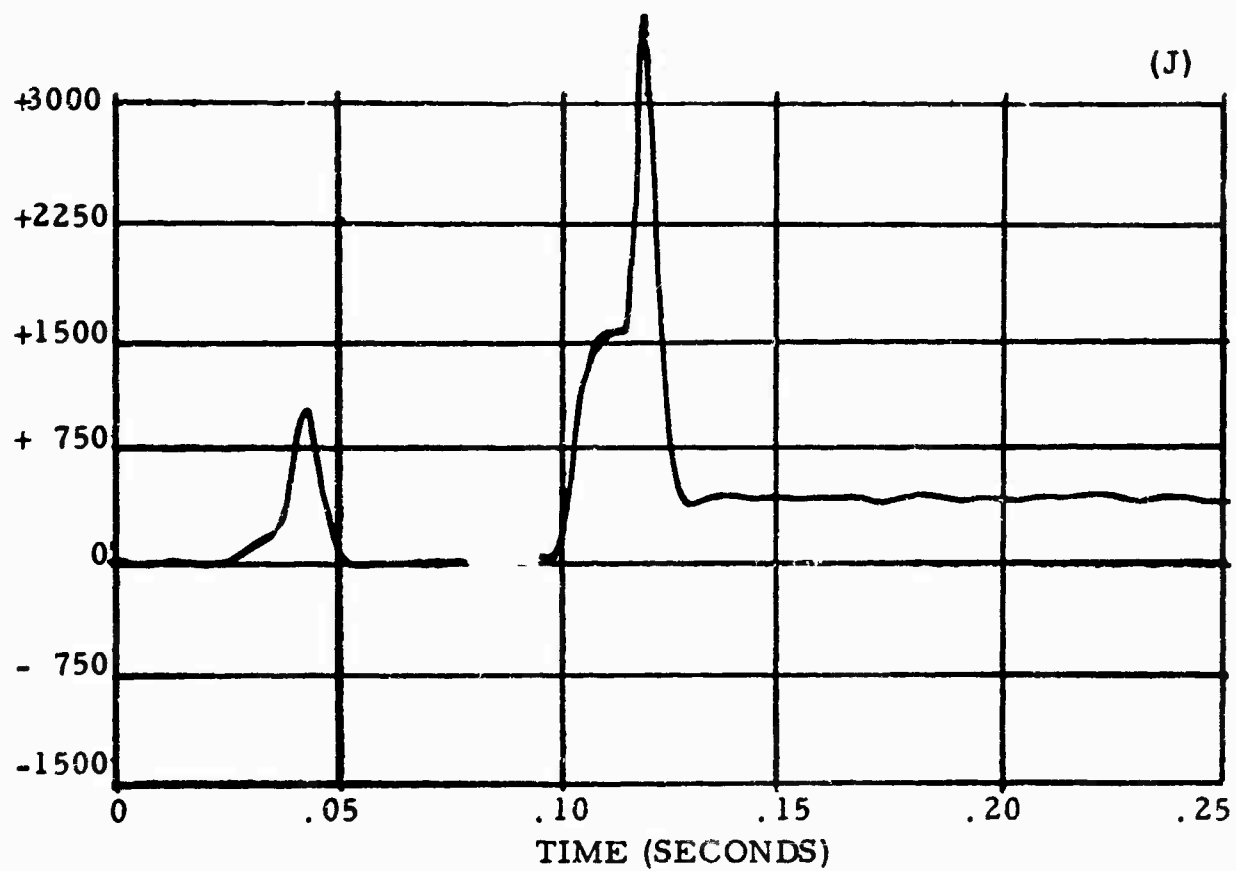RIGHT HAND SEAT BELT FORCE (H)
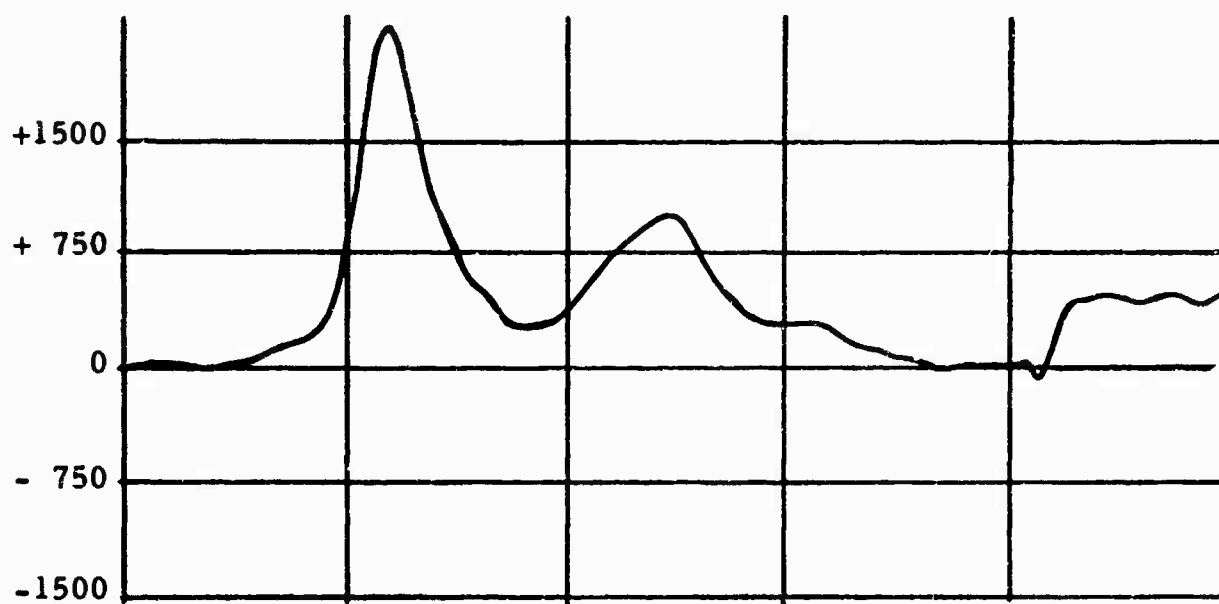
LEFT HAND SEAT BELT FORCE (I)
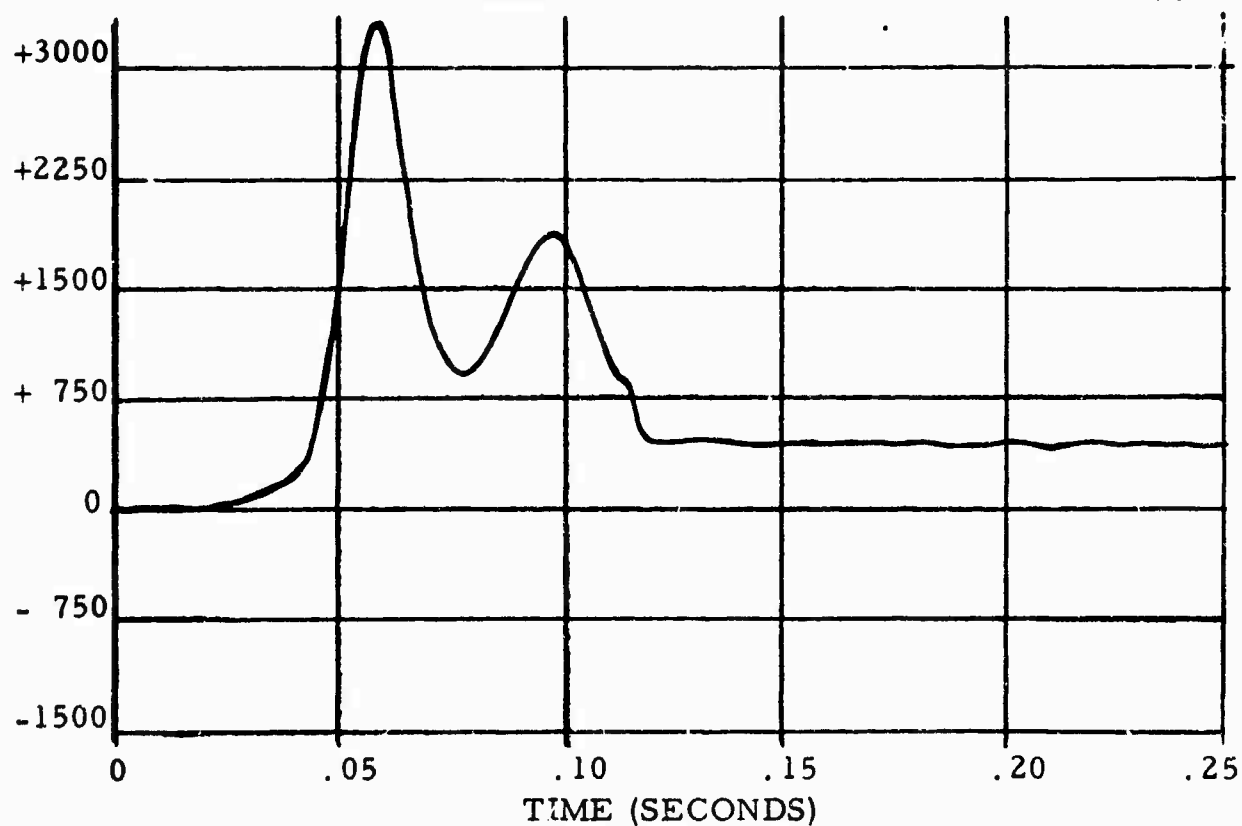
Figure 34 (contd.). Data Time Histories - Sikorsky Seat - Test Condition No. 1.
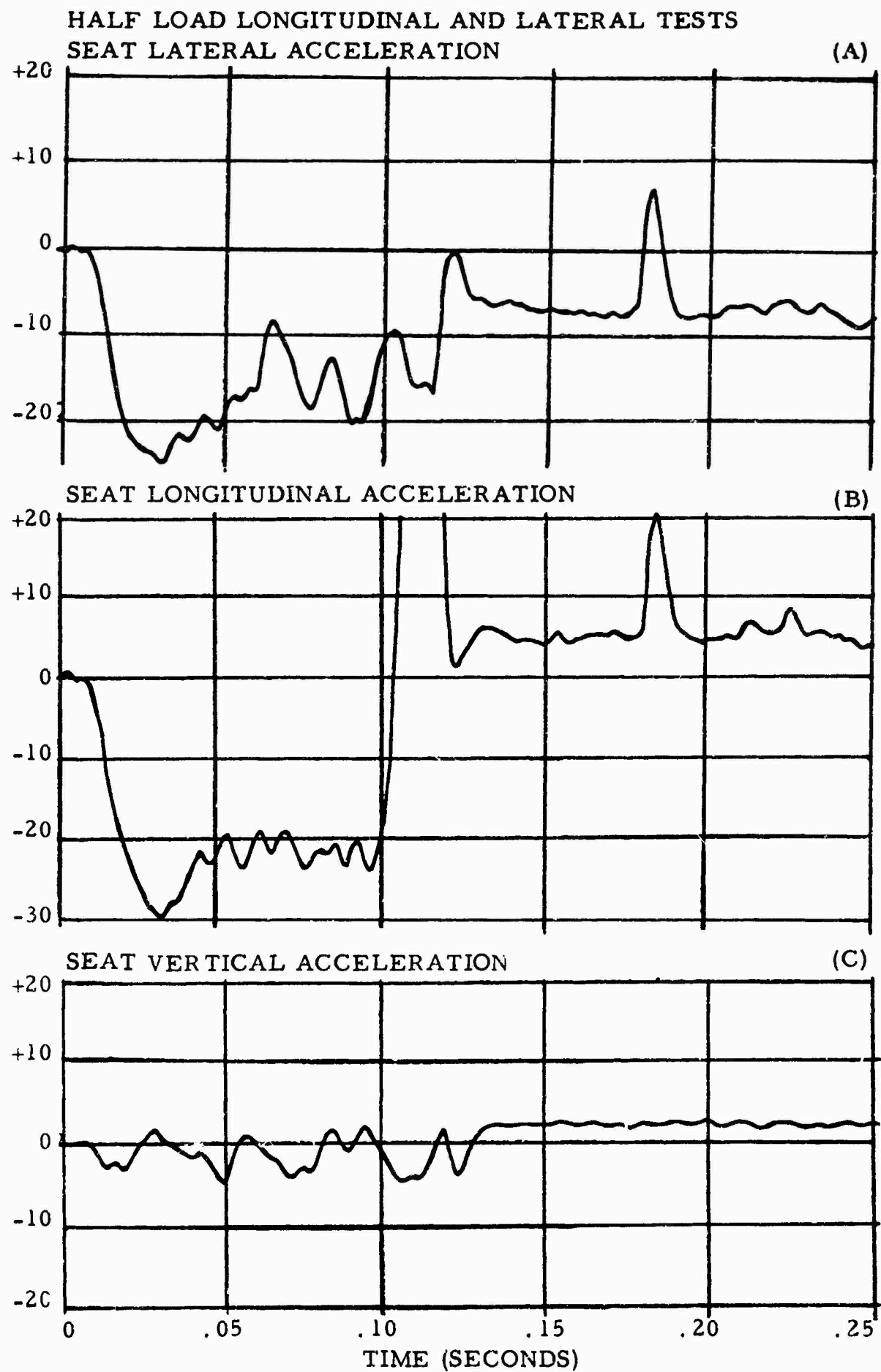
Figure 35. Data Time Histories - Sikorsky Seat -
Test Condition No. 2.
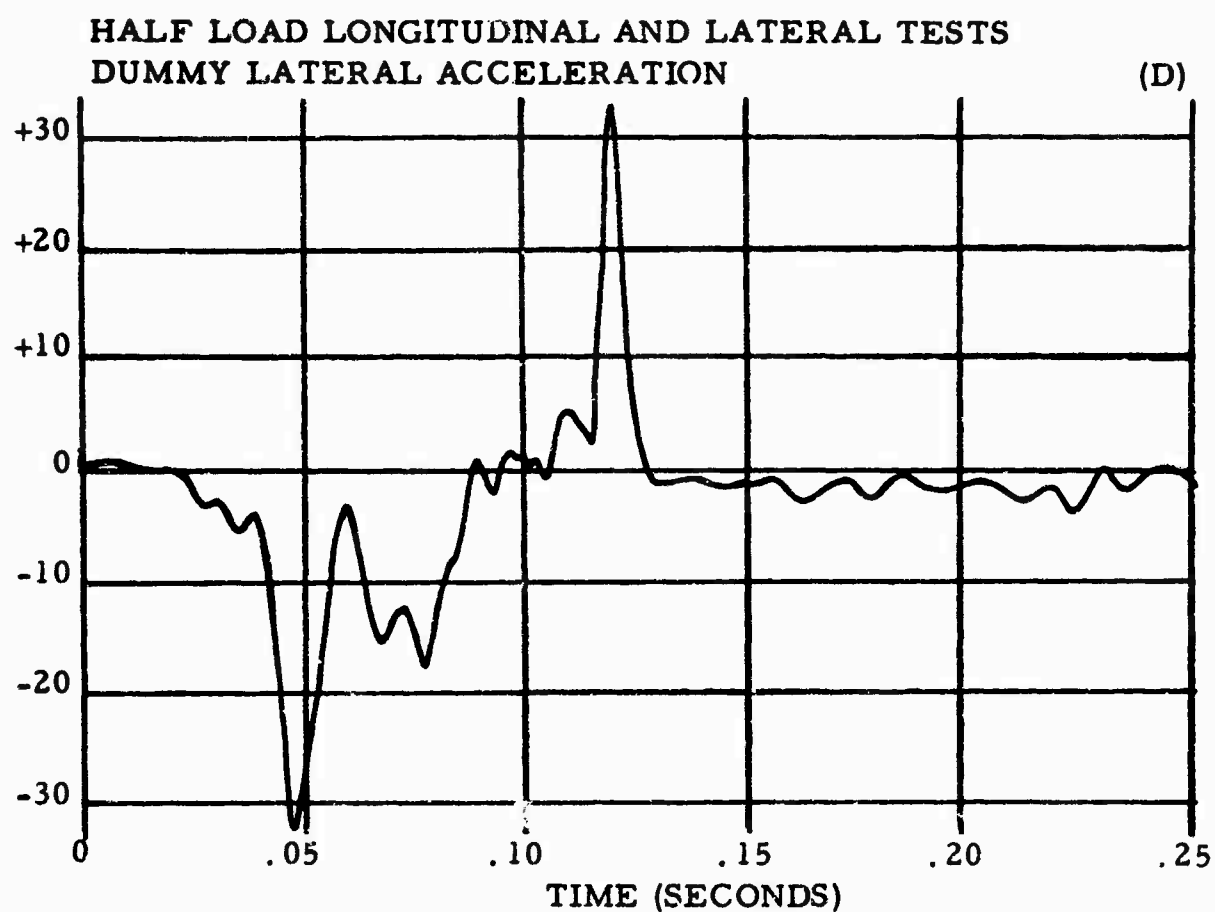
79

HALF LOAD LONGITUDINAL AND LATERAL TESTS
DUMMY LATERAL ACCELERATION

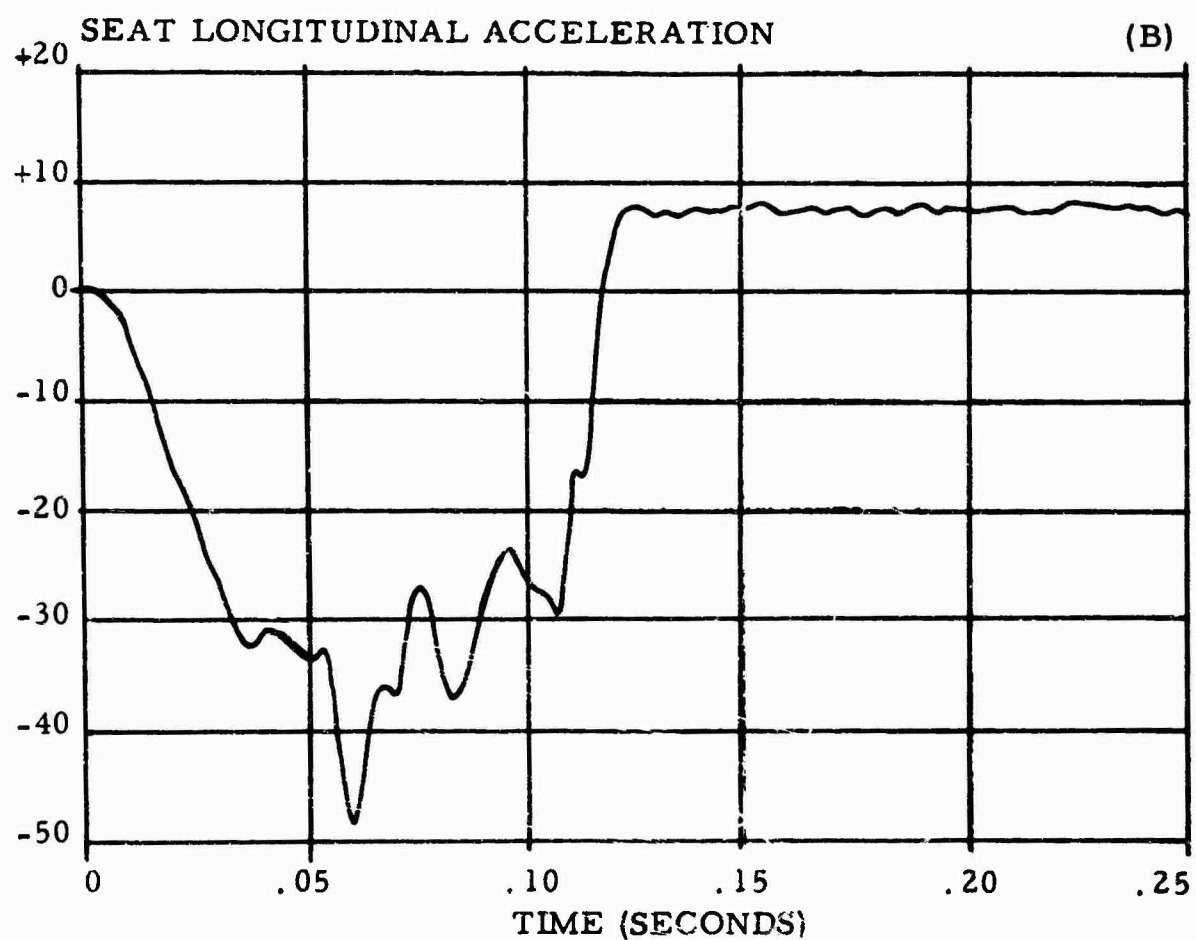Figure 35 (contd.). Data Time Histories - Sikorsky Seat - Test Condition No. 2.

HALF LOAD LONGITUDINAL AND LATERAL TESTS
DUMMY LONGITUDINAL ACCELERATION   (E)

Figure 35 (contd.). Data Time Histories - Sikorsky Seat -
Test Condition No. 2.

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HALF LOAD LONGITUDINAL AND LATERAL TESTS
DUMMY VERTICAL ACCELERATION (F)

SHOULDER HARNESS FORCE (G)

TIME (SECONDS)

Figure 35 (contd.). Data Time Histories - Sikorsky Seat -
Test Condition No. 2.

Figure 35 (contd.). Data Time Histories - Sikorsky Seat -
Test Condition No. 2.

HALF LOAD LONGITUDINAL AND LATERAL TESTS
LEFT HAND SEAT BELT FORCE

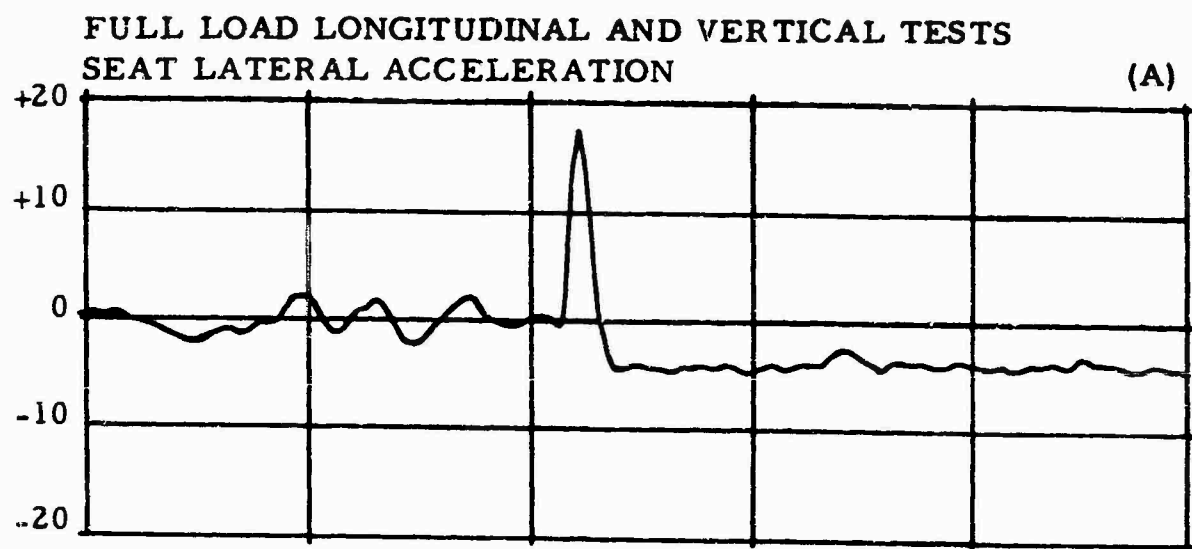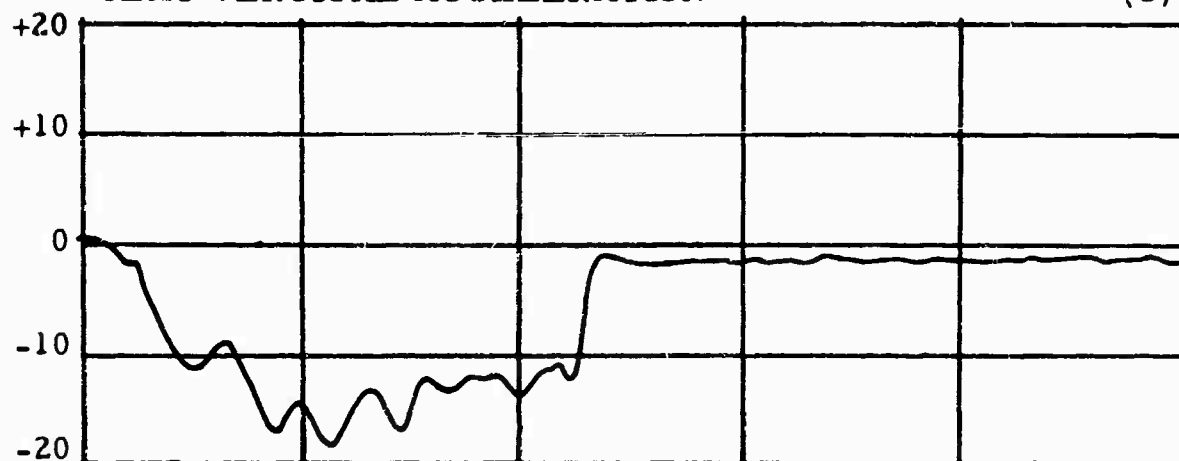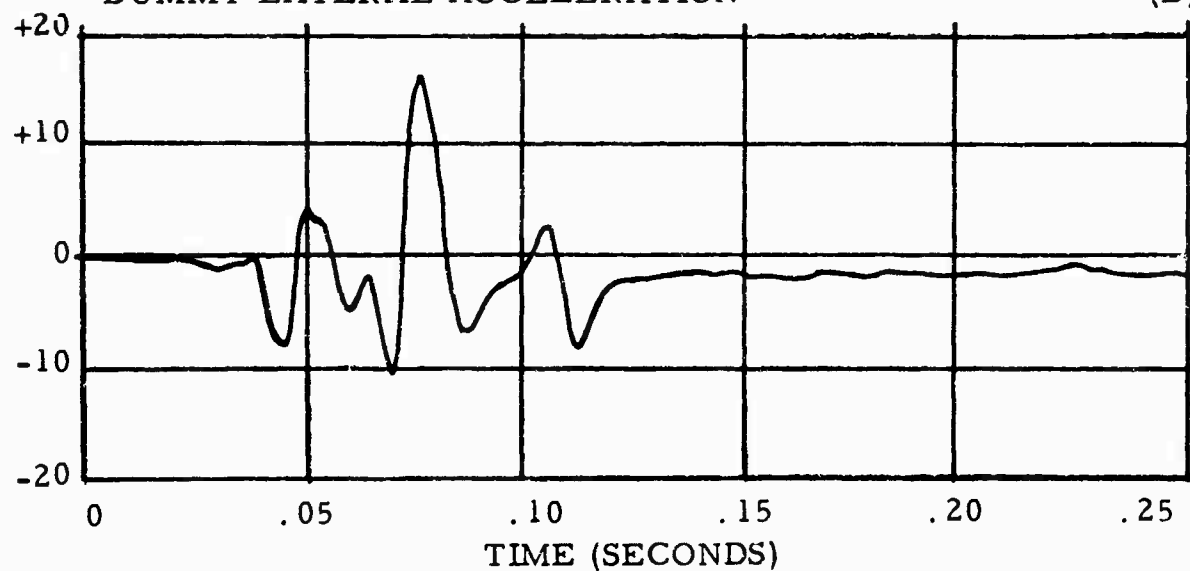Figure 35 (contd.). Data Time Histories - Sikorsky Seat - Test Condition No. 2.

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FULL LOAD LONGITUDINAL AND VERTICAL TESTS
SEAT LATERAL ACCELERATION (A)

SEAT LONGITUDINAL ACCELERATION (B)

TIME (SECONDS)

Figure 36.   Data Time Histories - Sikorsky Seat -
Test Condition No. 3.

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FULL LOAD LONGITUDINAL AND VERTICAL TESTS
SEAT VERTICAL ACCELERATION   (C)

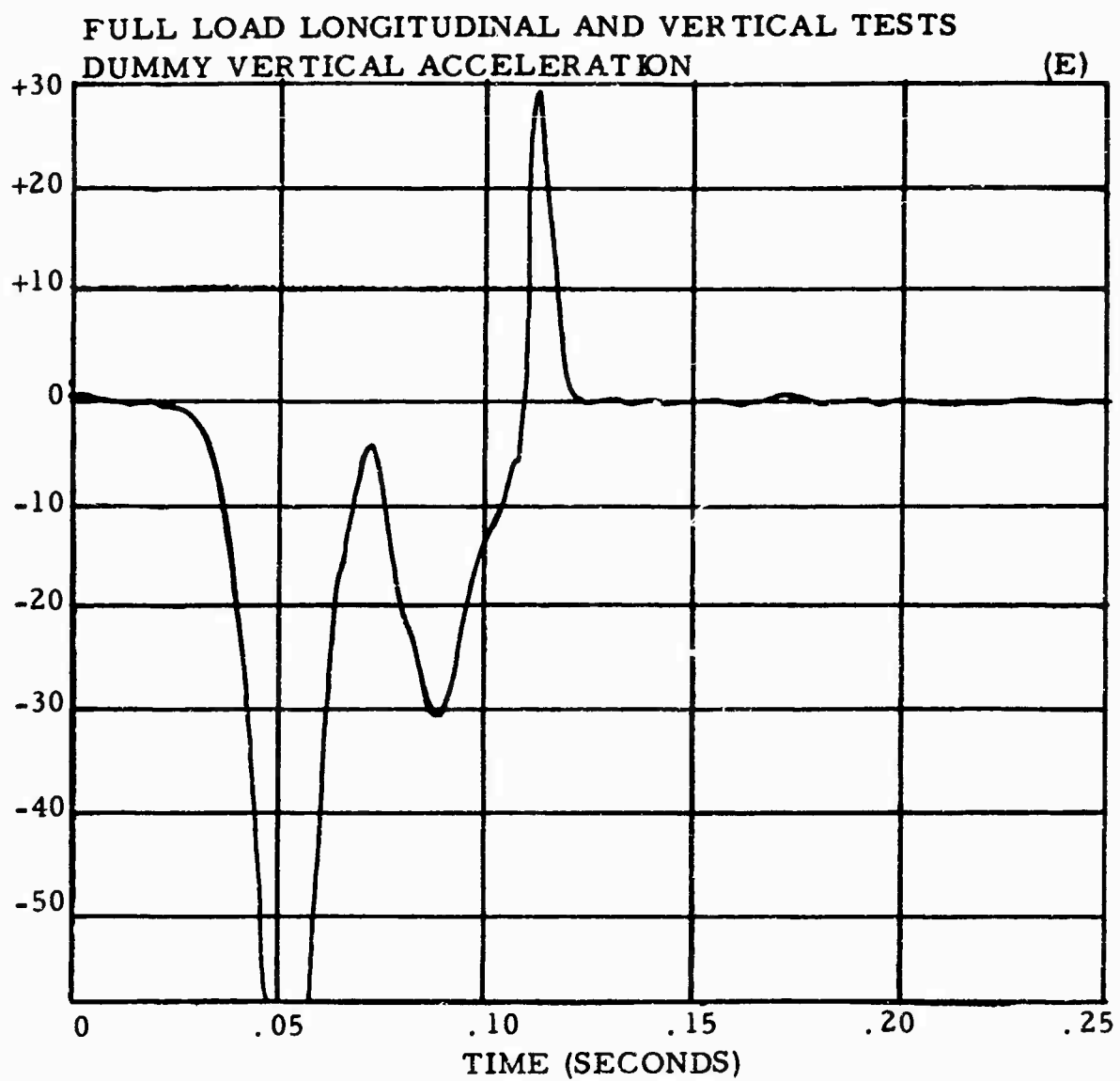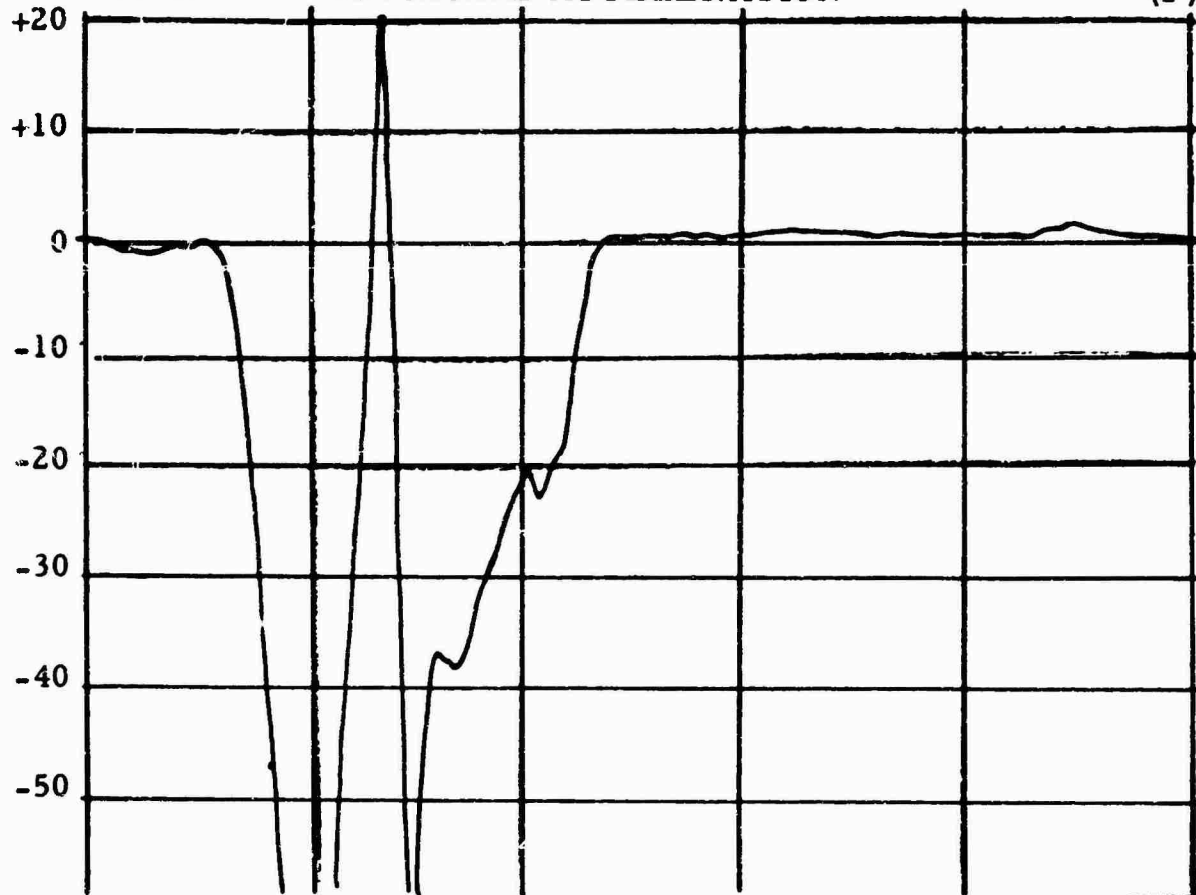DUMMY LATERAL ACCELERATION   (D)

TIME (SECONDS)

Figure 36 (contd.). Data Time Histories - Sikorsky Seat -
Test Condition No. 3.

86

FULL LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY VERTICAL ACCELERATION   (E)

Figure 36 (contd.). Data Time Histories - Sikorsky Seat -
Test Condition No. 3.

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FULL LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY LONGITUDINAL ACCELERATION
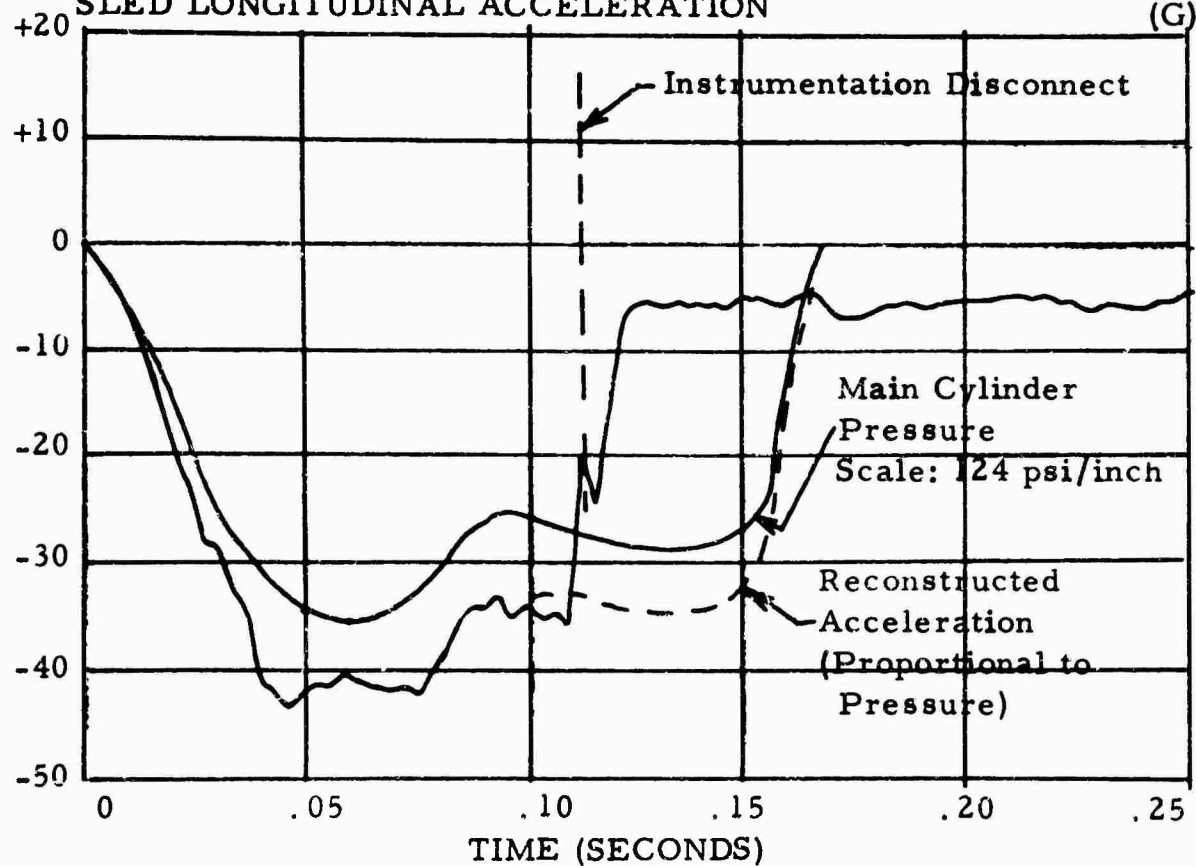
(F)

SLED LONGITUDINAL ACCELERATION

(G)

TIME (SECONDS)

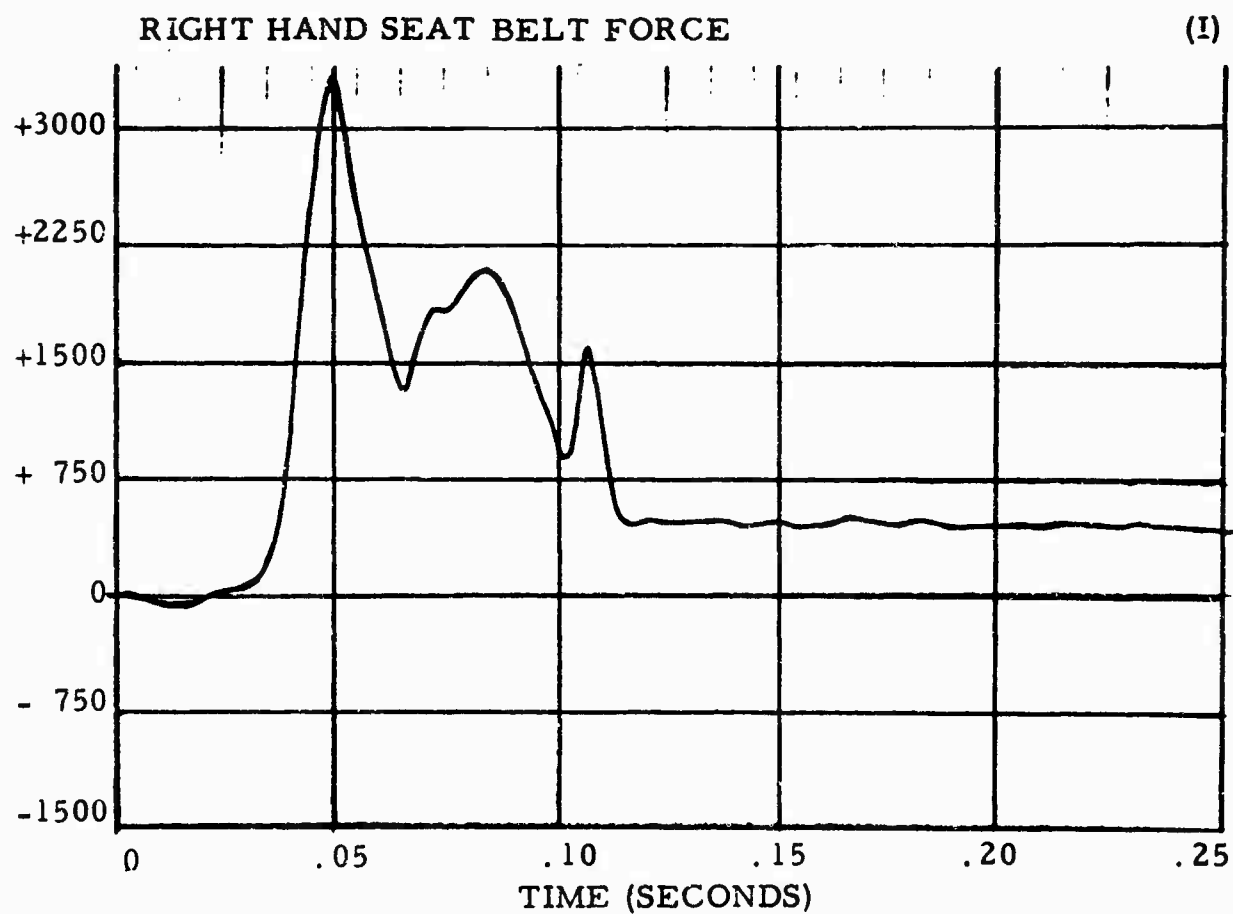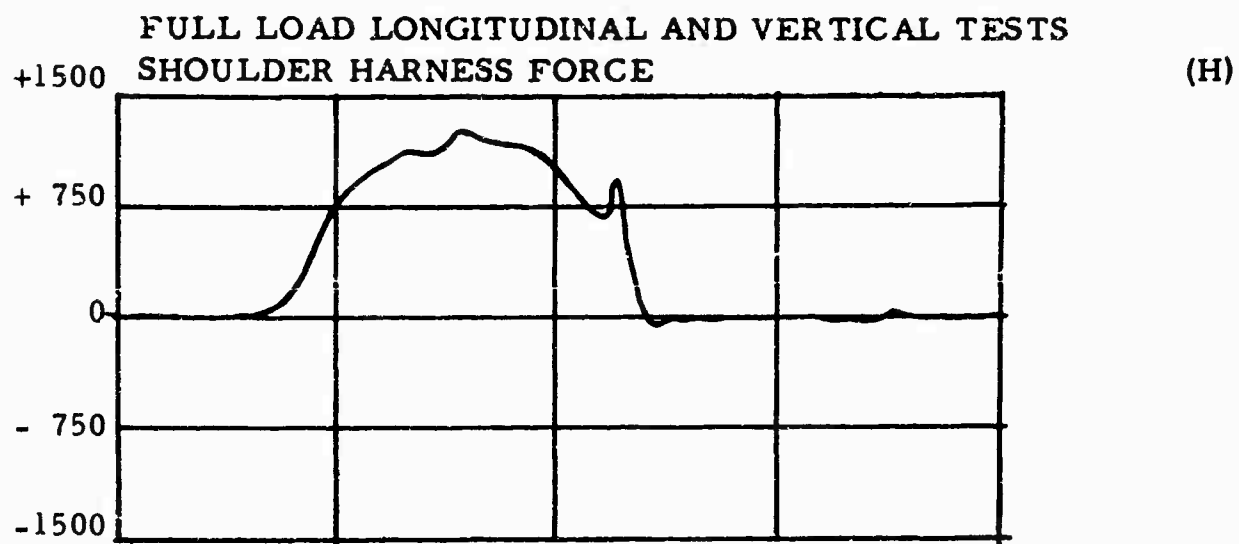Figure 36 (contd.). Data Time Histories - Sikorsky Seat -
Test Condition No. 3.

FULL LOAD LONGITUDINAL AND VERTICAL TESTS
SHOULDER HARNESS FORCE   (H)

RIGHT HAND SEAT BELT FORCE   (I)

TIME (SECONDS)

Figure 36 (contd.). Data Time Histories - Sikorsky Seat -
Test Condition No. 3.

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FULL LOAD LONGITUDINAL AND VERTICAL TESTS
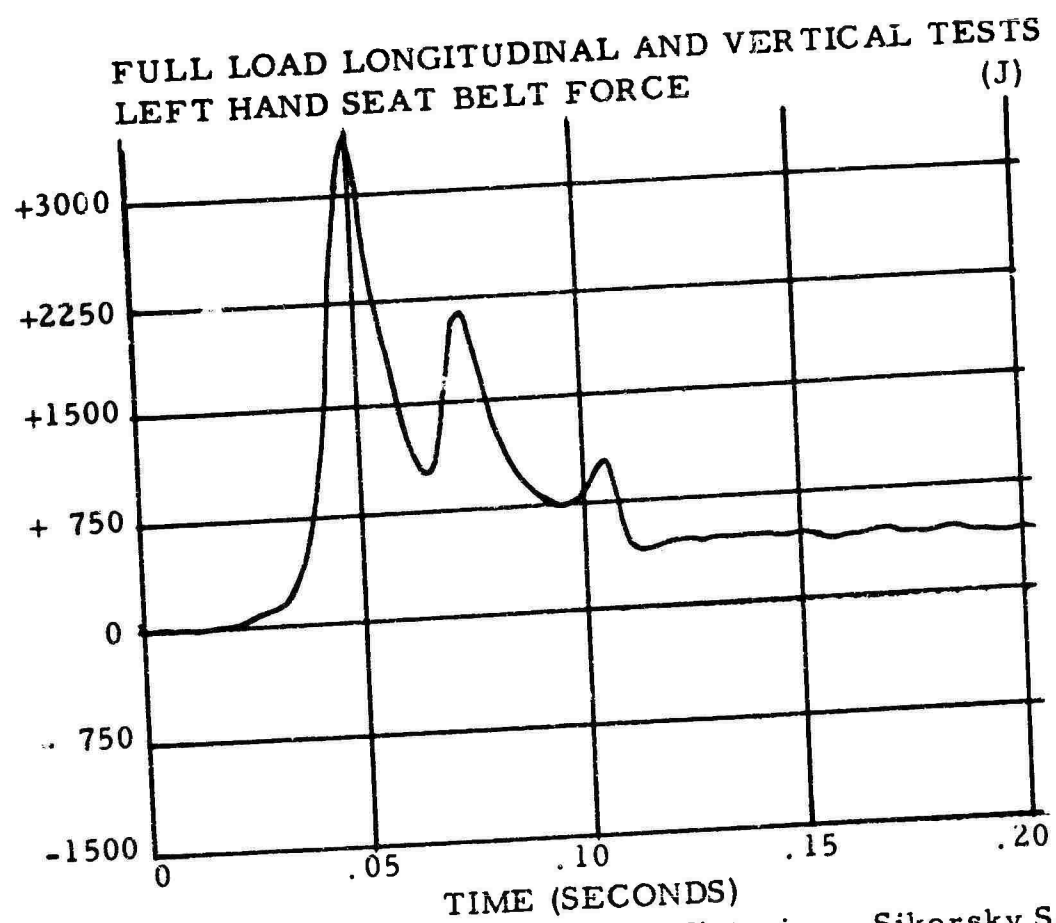LEFT HAND SEAT BELT FORCE

Figure 36 (contd.). Data Time Histories - Sikorsky Seat -
Test Condition No. 3.

The shoulder harness load for the full-load test, Figure 36I, is, however, less than the load recorded in the half-load test, Figure 34F. This is not what might be anticipated but is probably due to the vertical accelerations being simultaneously imposed. This same situation has been experienced in past helicopter crash tests in which high vertical accelerations were experienced.

SIKORSKY SEAT TEST CONDITION NO. 4

The final Sikorsky test was a full-load test with the seat oriented 45 degrees left of the thrust axis. The seat again stayed in place, with the only damage being a slight bending of the right side armor plate. A sequence photograph of the test is presented in Figure 37, and a posttest photograph is shown in Figure 38.

The acceleration records obtained are presented in Figures 40A through 40F and are valid to t = 0.085 second at which time an instrumentation disconnect occurred.

The agreement between sled acceleration and cylinder pressure up to 0.085 second is very good as seen in Figure 40F. The seat lateral acceleration component, about 26G maximum, Figure 40A, also closely follows sled longitudinal pulse. The dummy longitudinal acceleration is given in Figure 40D nd appears to be maintained at about 30G (after a 62G peak at t = 0.045 second) prior to the instrumentation disconnect. This value of 30G longitudinal is very close to the component of the sled acceleration, that is, 38G x Cos 45 degrees = 27G.

The dummy lateral acceleration, Figure 40C, reached about 36G prior to the disconnect, which implies a dynamic amplification factor of about 36 ÷ 27 = 1.3

VERTOL SEAT TEST CONDITION NO. 1

In this test, the seat was oriented 28 degrees upward from horizontal to impose the desired horizontal and vertical loads during the initial phases of the test. The sled moved about 15 inches before the dummy began to move. Shortly thereafter, seat belt and shoulder harness failures occurred, resulting in the dummy's being ejected from the seat. Figure 39 is a posttest view of the empty seat. Figure 41 shows the slight damage to the energy absorption blocks. Inspection showed that the seat belt had failed by shearing out the seat pan to seat belt attachment
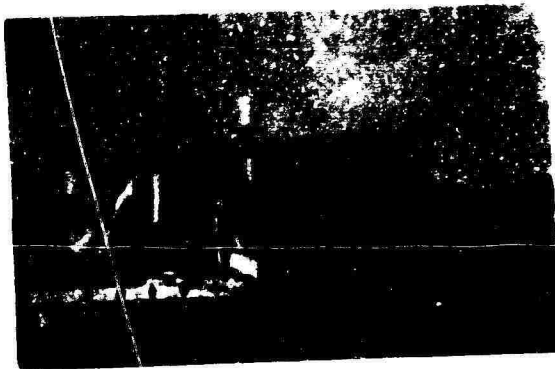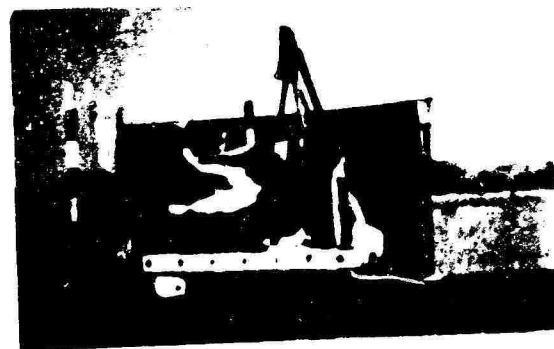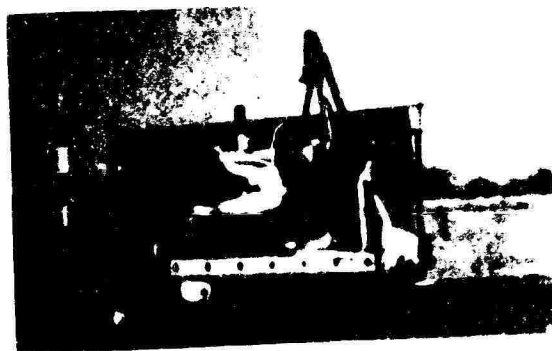
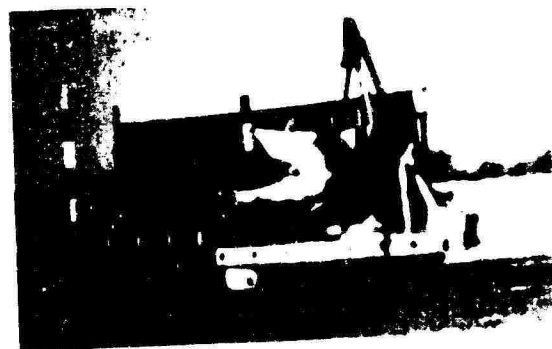t = 0.0 sec.; first motion
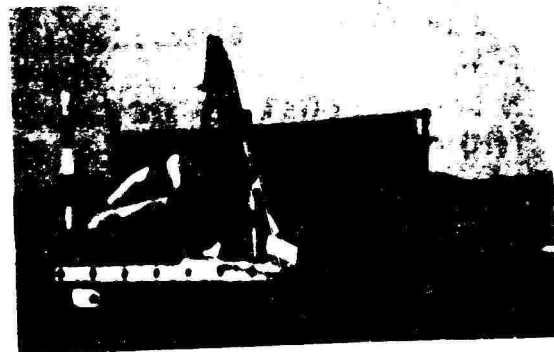
t = 0.039 sec.; sled movement, 1 ft.

t = 0.058 sec.; sled movement, 2 ft.

t = 0.073 sec.; sled movement, 3 ft.

t = 0.083 sec.; sled movement, 4 ft.

t = 0.094 sec.; (instrumentation has disconnected)

Figure 37. Sequence Photographs of Sikorsky Seat - Test Condition No. 4.

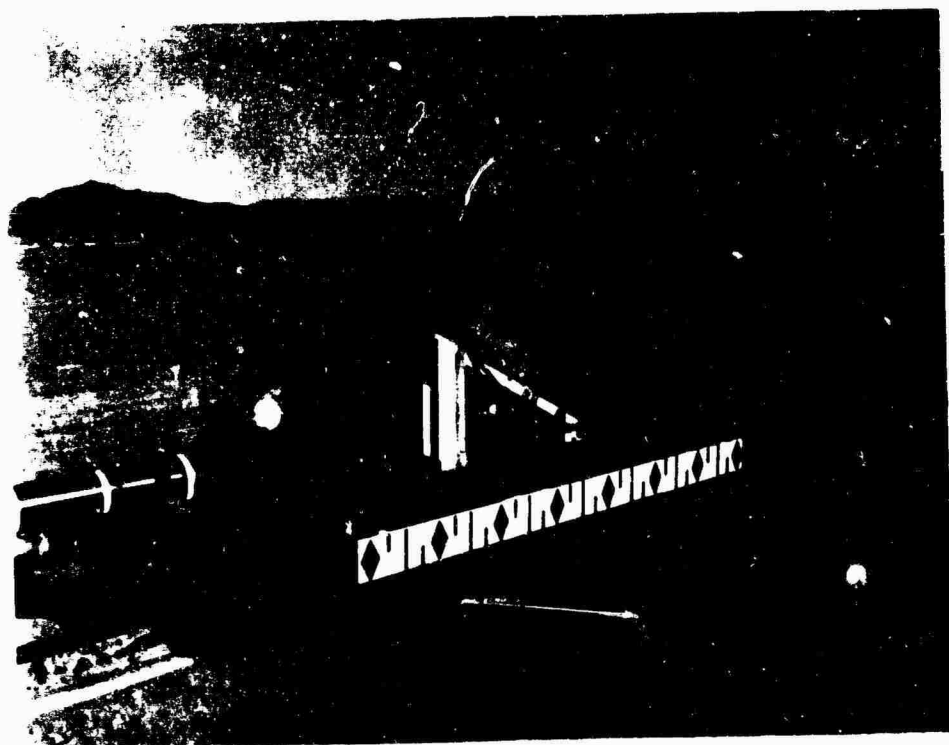Figure 38. Posttest View of Sikorsky Seat - Test Condition No. 4.

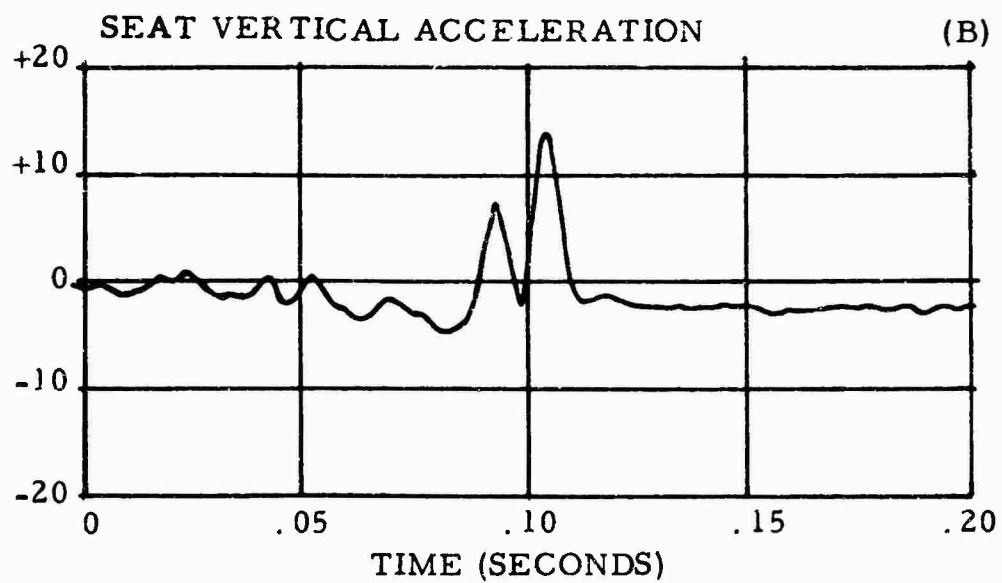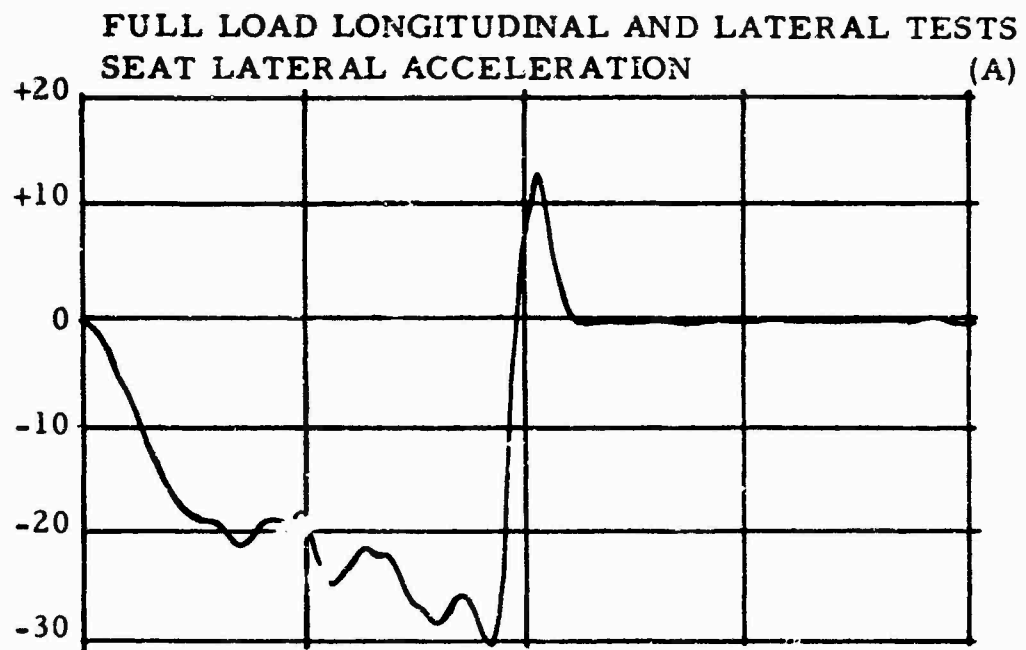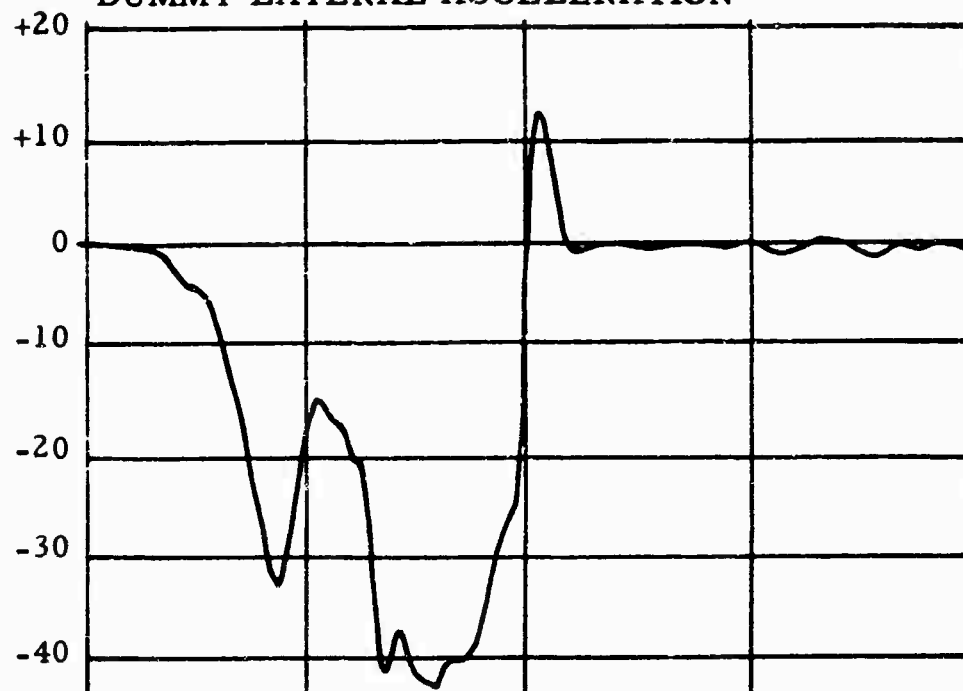Figure 39. Posttest View of Vertol Seat - Test Condition No. 1.

FULL LOAD LONGITUDINAL AND LATERAL TESTS
SEAT LATERAL ACCELERATION (A)

SEAT VERTICAL ACCELERATION (B)

TIME (SECONDS)

Figure 40. Data Time Histories - Sikorsky Seat - Test Condition No. 4.

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FULL LOAD LONGITUDINAL AND LATERAL TESTS
DUMMY LATERAL ACCELERATION   (C)
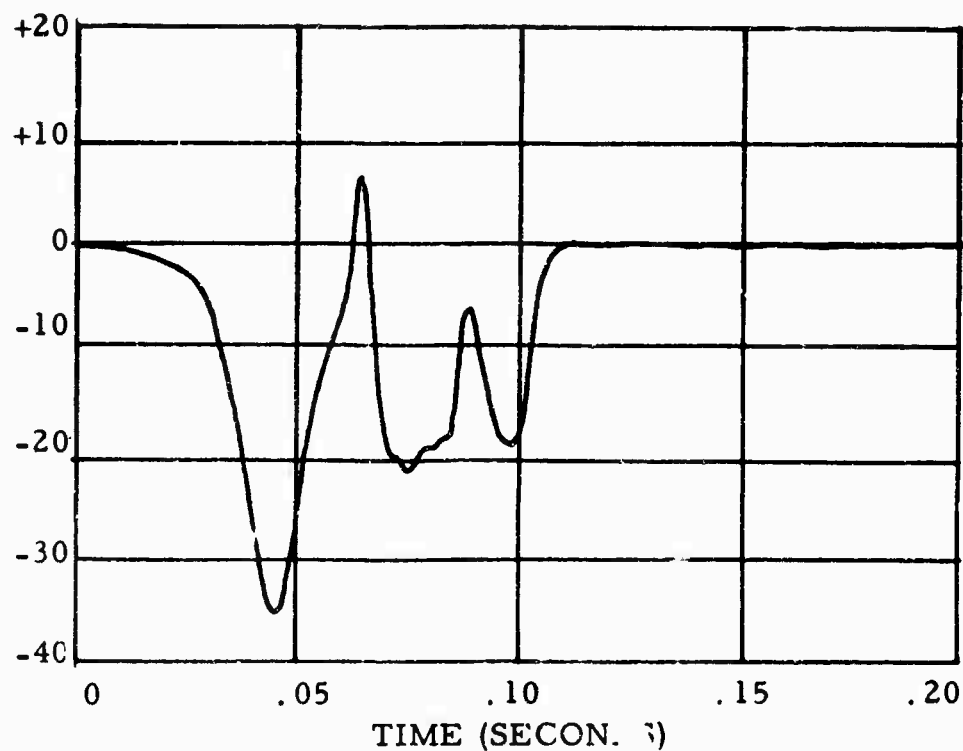
DUMMY LONGITUDINAL ACCELERATION   (D)

TIME (SECON. 3)

Figure 40 (contd.). Data Time Histories - Sikorsky Seat -
Test Condition No. 4.

FULL LOAD LONGITUDINAL AND LATERAL TESTS
DUMMY VERTICAL ACCELERATION (E)

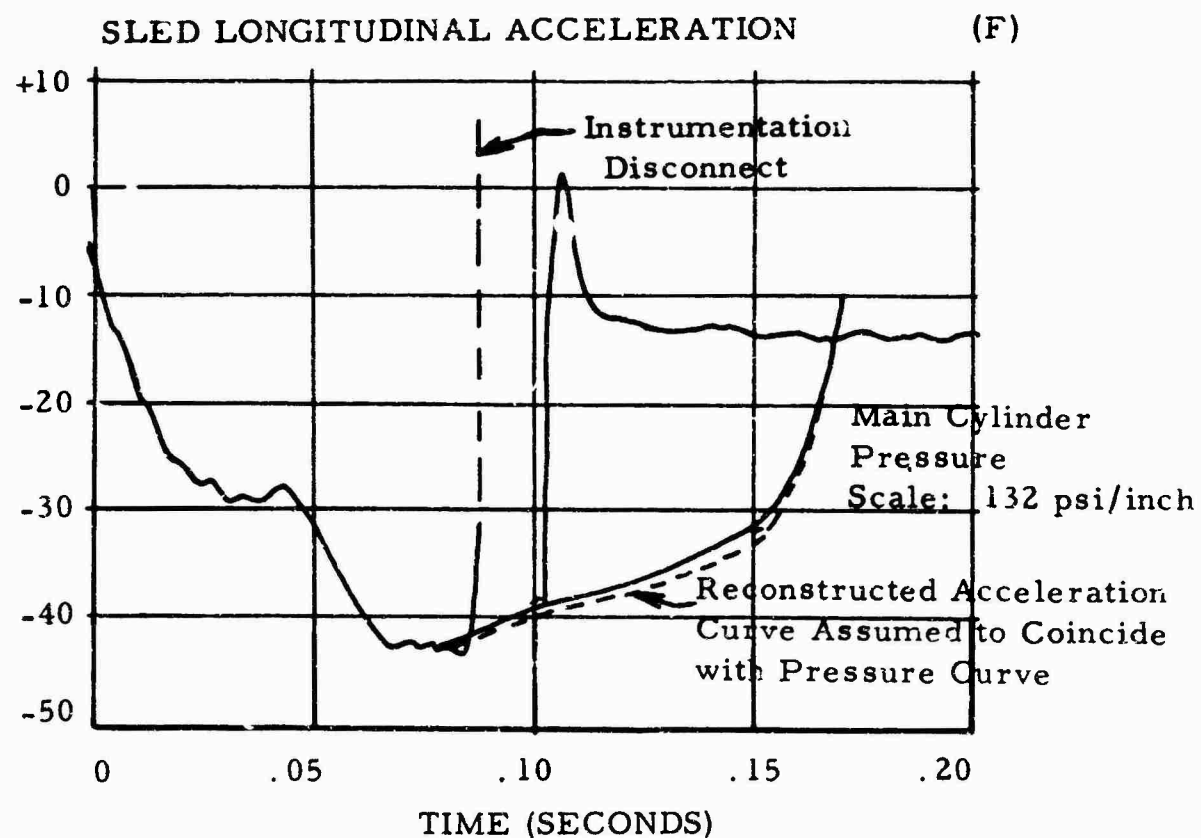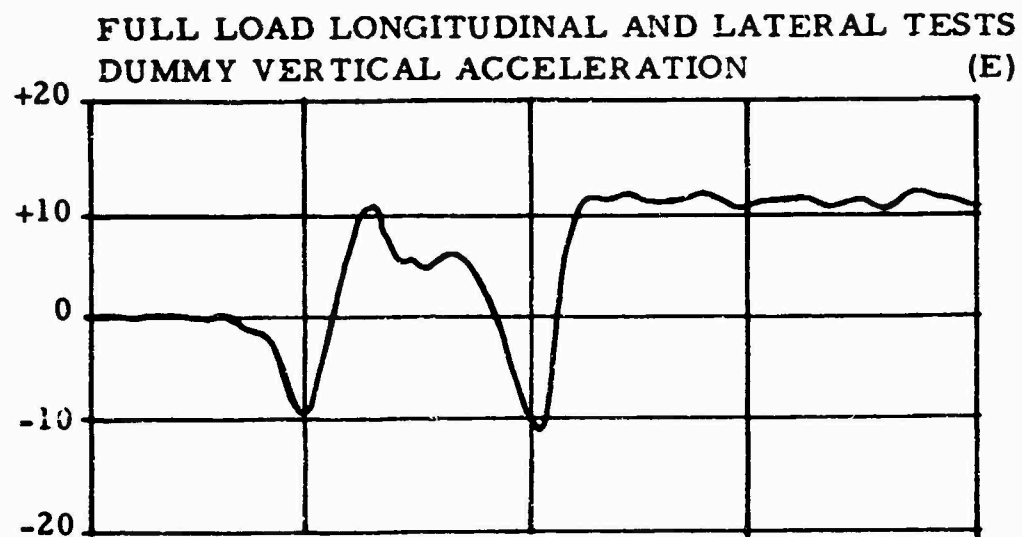## SLED LONGITUDINAL ACCELERATION (F)

TIME (SECONDS)

Figure 40 (contd.). Data Time Histories - Sikorsky Seat - Test Condition No. 4.

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plate on the right side. The right-hand portion of the seat belt was deposited 45 feet from the initial position while the sled traveled 548 feet, which indicates an early failure of the seat belt. Other components were spread along the sled path, with the dummy coming to rest at 150 feet. The shoulder harness had failed at the adjustment fitting. The chest armor also was disengaged prior to the dummy's leaving the sled.

The sled acceleration pulse, Figure 43J, shows a 20G trapezoid on which is superimposed a half sine-wave pulse of about 0.030 second. The peak acceleration was approximately 30G. The seat longitudinal acceleration, Figure 43B, is in good agreement with these values. The seat vertical acceleration, Figure 43C, agrees only near the beginning of the pulse; this indicates that appreciable seat deflection must have occurred.

The dummy pelvic accelerations, Figures 43E and 43F, are, of course, affected by the seat belt and shoulder harness failures which occurred between 0.08 and 0.11 second and the subsequent motion of the dummy.

The seat belt loads (one side), as shown in Figure 43G, did not exceed about 1600 pounds prior to failure of seat belt. The shoulder harness loads, Figure 43H, indicate that failure occurred after the seat belt failure. The maximum load reached was 1700 pounds.

VERTOL SEAT TEST CONDITION NO. 2

This test was run with the seat mounted 28 degrees left of the sled thrust axis. The sled moved about 18 inches before the dummy began to move; and shortly thereafter, the shoulder harness and one of the seat belt fittings failed. A posttest examination of the seat showed the dummy jackknifed over the lap belt and leaning to the left owing to failure of the shoulder harness and seat belt fittings, as shown in Figure 42. Figure 44 shows seat belt tiedown fitting failure. The shoulder harness failed at the point where the web strap passed over the rollers in the harness adjust fitting. The eccentric loading on the seat was sufficient to cause minor crushing of the vertical attenuators on the right side of the seat. The deformation of the absorbers was not sufficient to effect subsequent tests, and repair of the seat was made. The basic pulse was a skewed trapezoid, as shown in Figure 46G. The sled acceleration was 20G maximum with corresponding component of 17G longitudinal and 9G lateral measured with respect to the seat itself. The measured seat accelerations are presented in Figures 46A and 46B and are in good agreement with the sled values. Figure 46C shows a typical seat vertical acceleration for all longitudinal-lateral combination tests. No vertical accelerations (other than those due to vibration) were recorded.

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Figure 41. Damage to Energy Absorber Blocks -
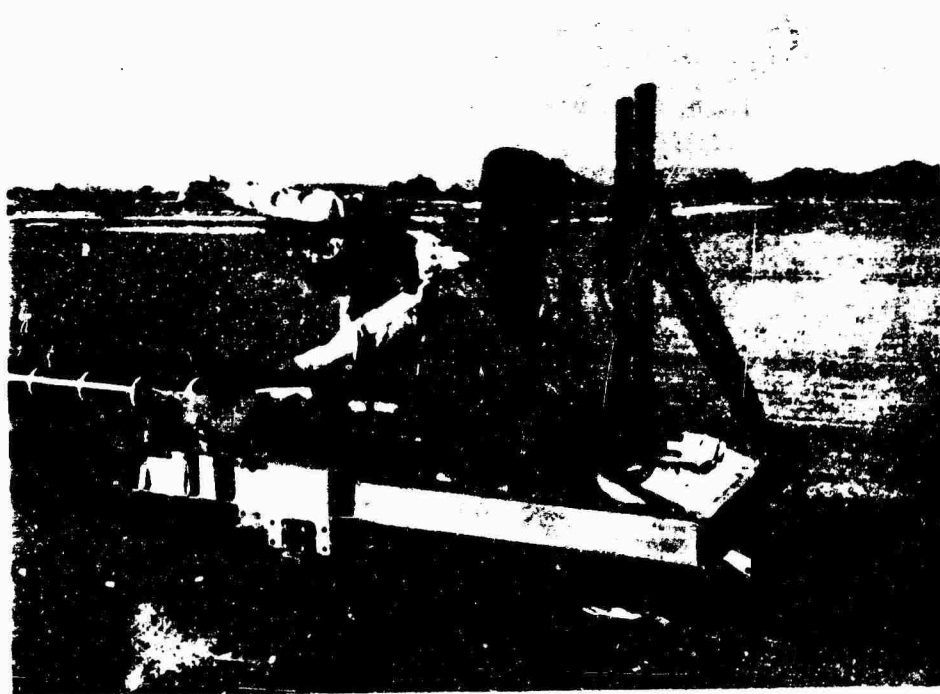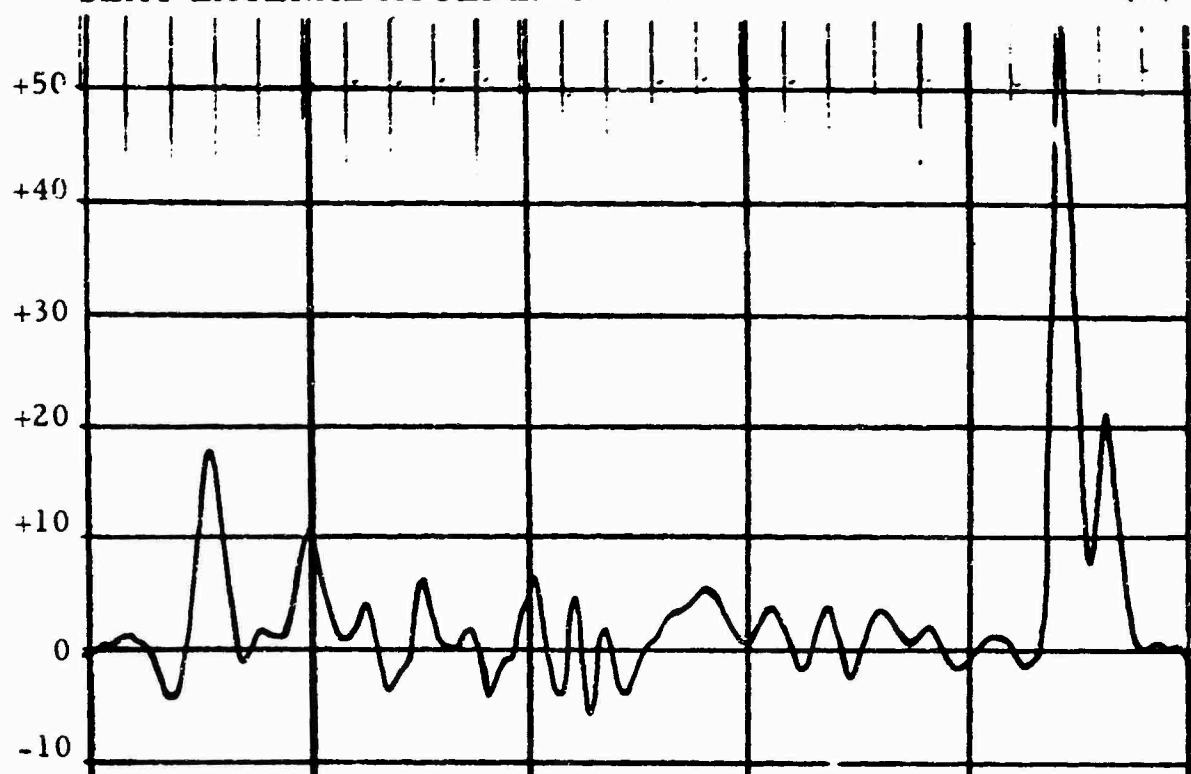Vertol Seat - Test Condition No. 1.

Figure 42. Posttest View of Vertol Seat - Test Condition No. 2.

HALF LOAD LONGITUDINAL AND VERTICAL TESTS

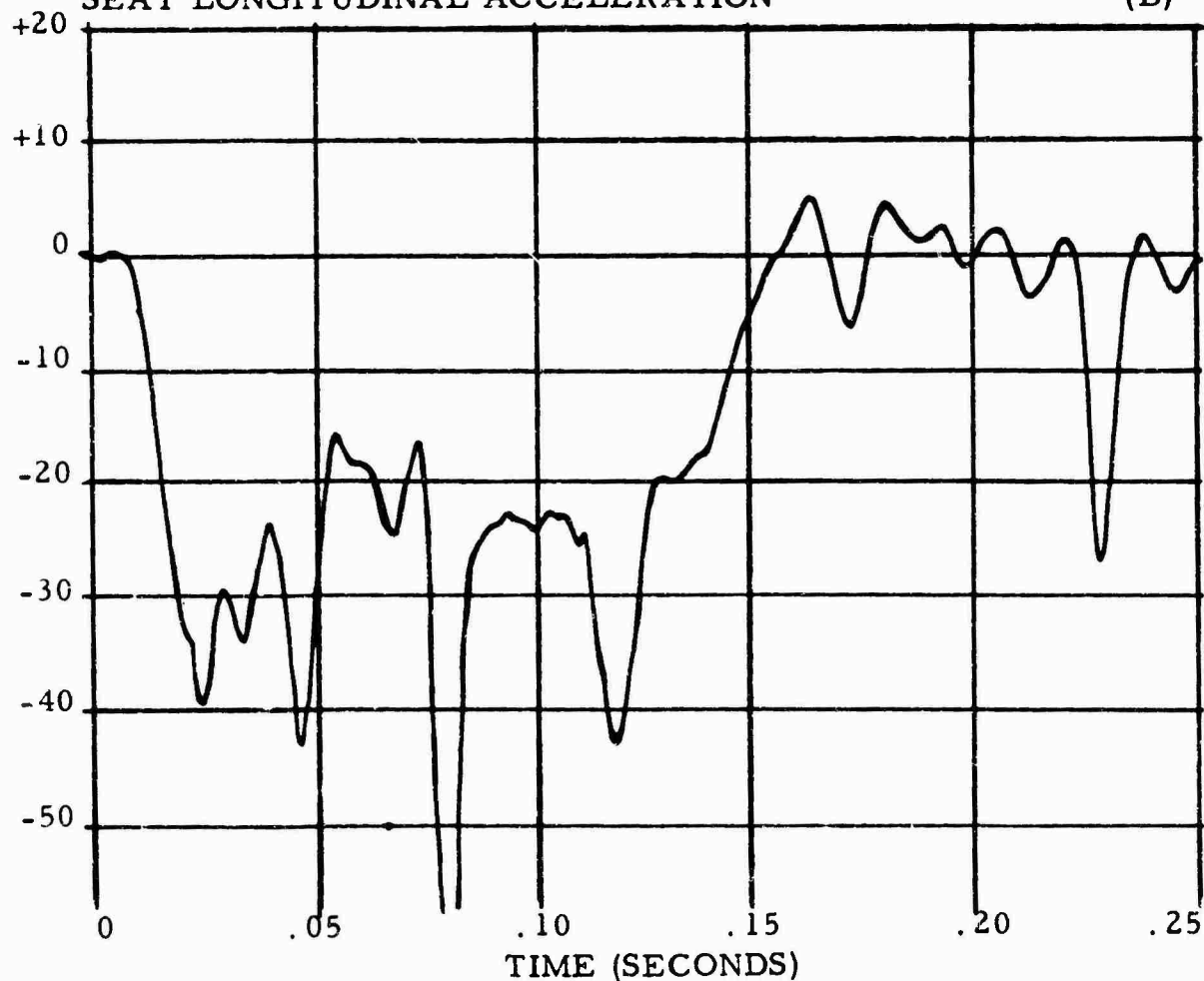## SEAT LATERAL ACCELERATION (A)

SEAT LONGITUDINAL ACCELERATION (B)

TIME (SECONDS)

Figure 43. Data Time Histories – Vertol Seat – Test Condition No. 1.

HALF LOAD LONGITUDINAL AND VERTICAL TESTS
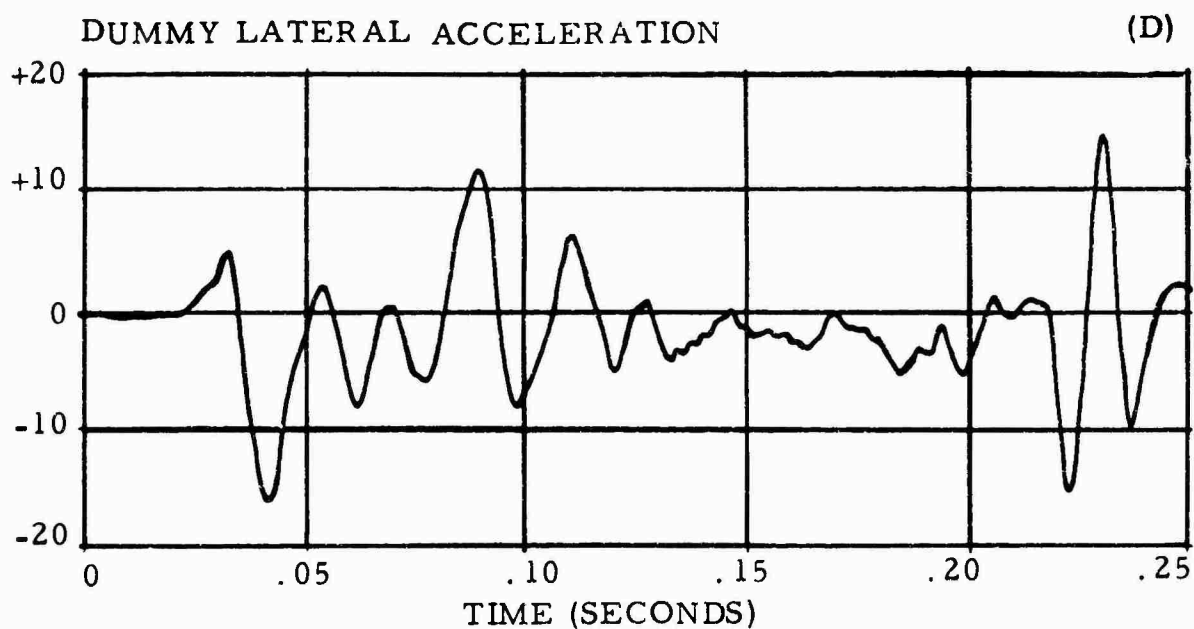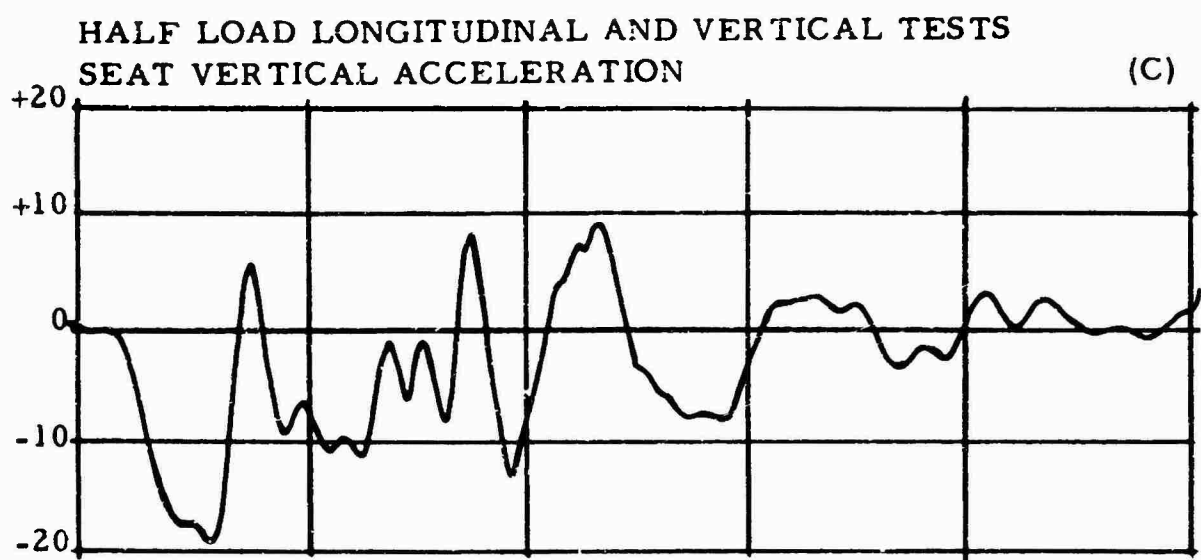## SEAT VERTICAL ACCELERATION

(C)

DUMMY LATERAL ACCELERATION

(D)

TIME (SECONDS)

Figure 43 (contd.). Data Time Histories - Vertol Seat -
Test Condition No. 1.

HALF LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY LONGITUDINAL ACCELERATION   (E)

DUMMY VERTICAL ACCELERATION   (F)

TIME (SECONDS)

Figure 43 (contd.). Data Time Histories - Vertol Seat -
Test Condition No. 1.

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HALF LOAD LONGITUDINAL AND VERTICAL TESTS
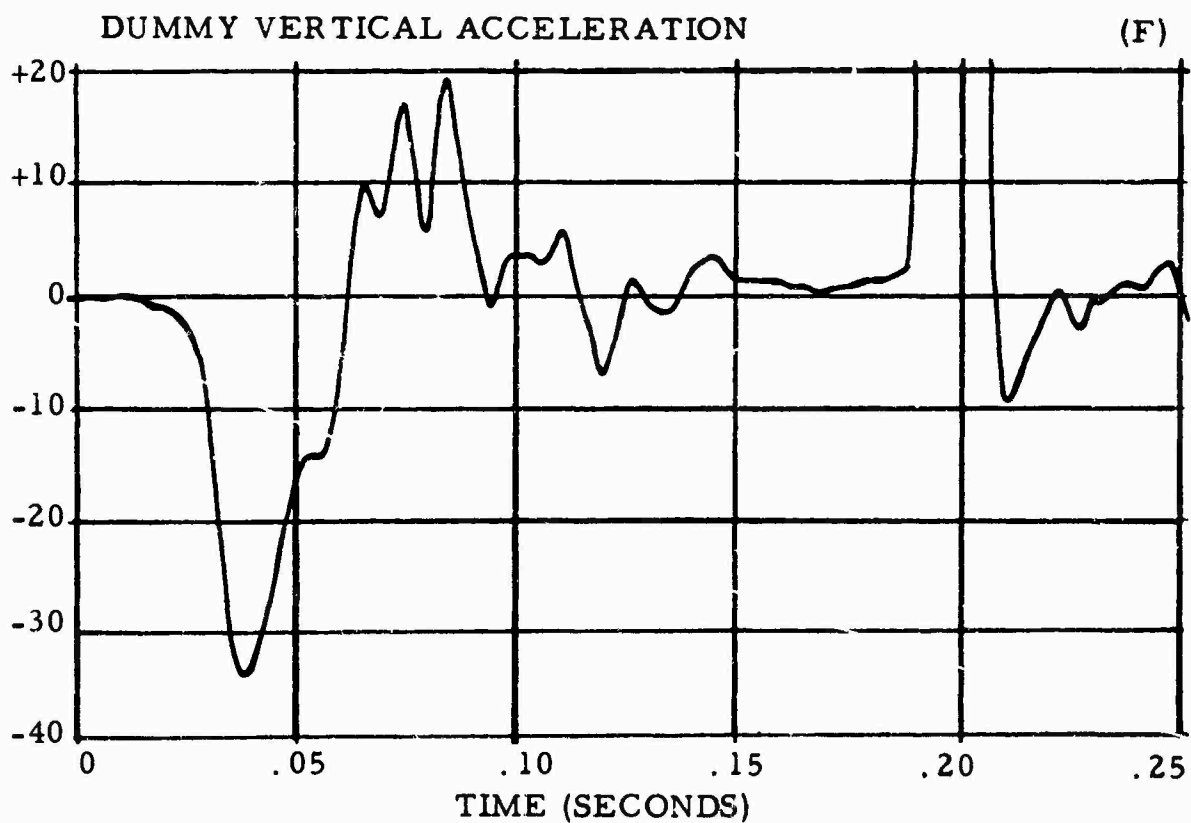SEAT BELT FORCE (G)

SHOULDER HARNESS FORCE (H)

TIME (SECONDS)

Figure 43 (contd.). Data Time Histories - Vertol Seat -
Test Condition No. 1.

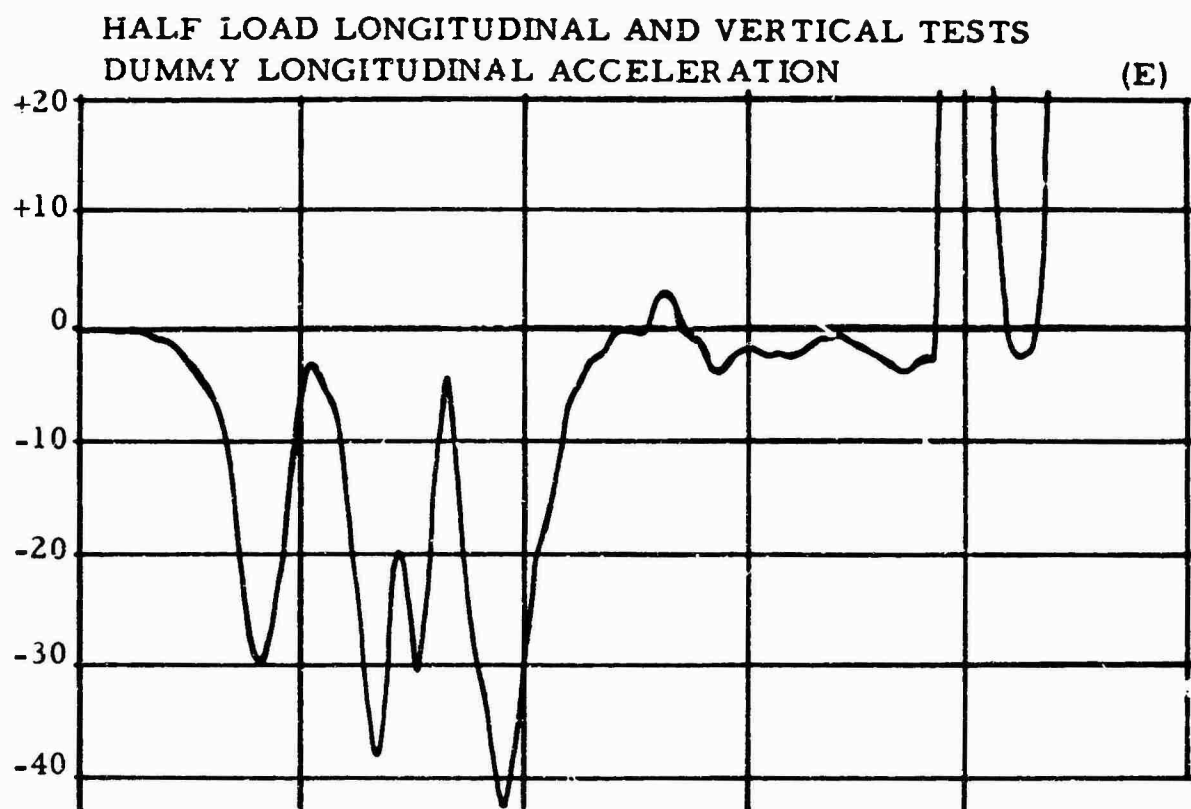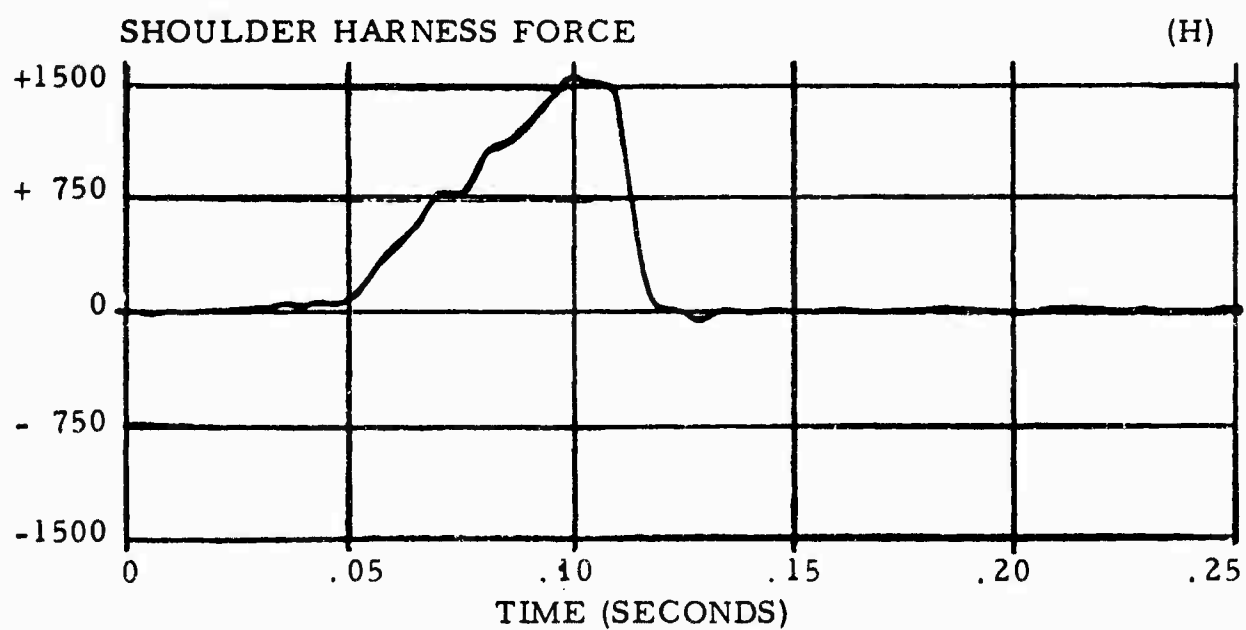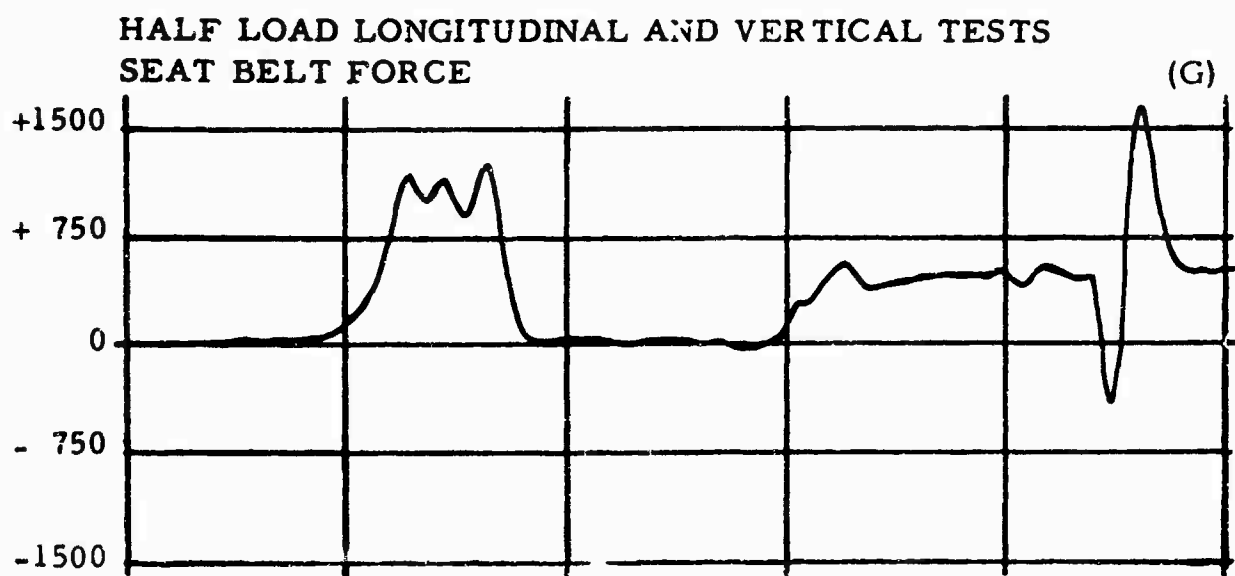## HALF LOAD LONGITUDINAL AND VERTICAL TESTS
SEAT RESTRAINT HARNESS FORCE   (I)

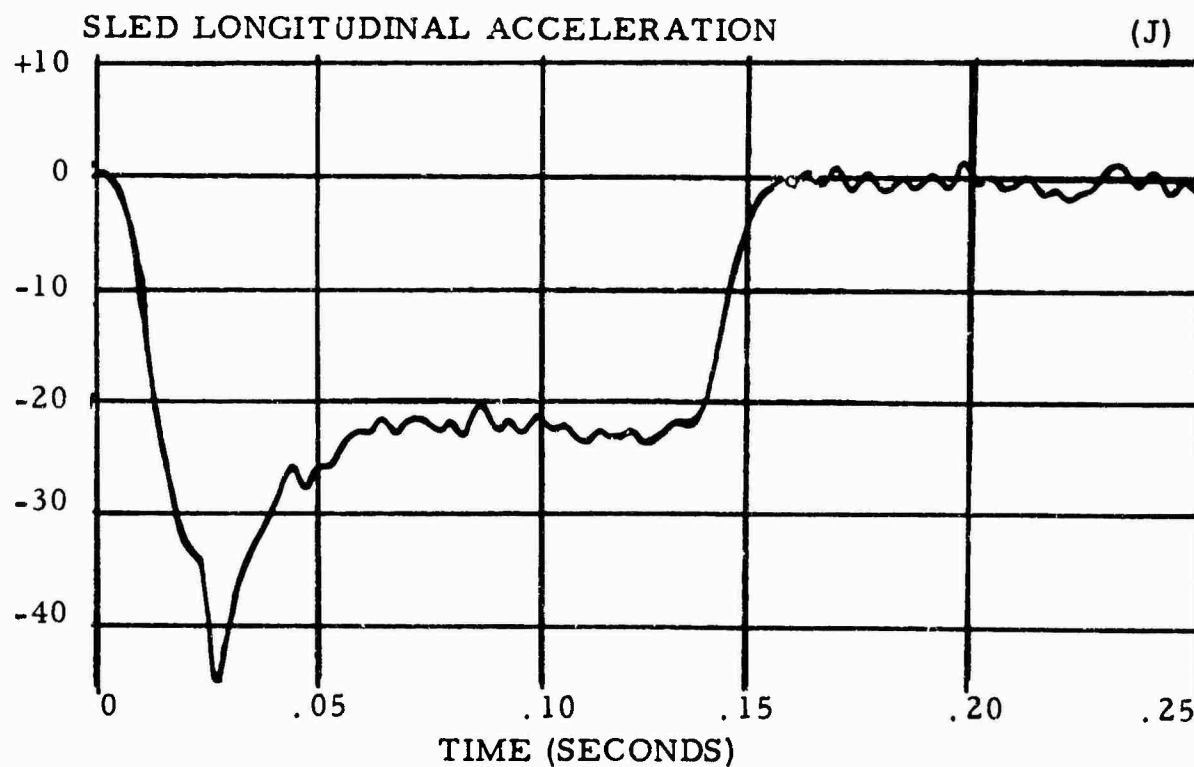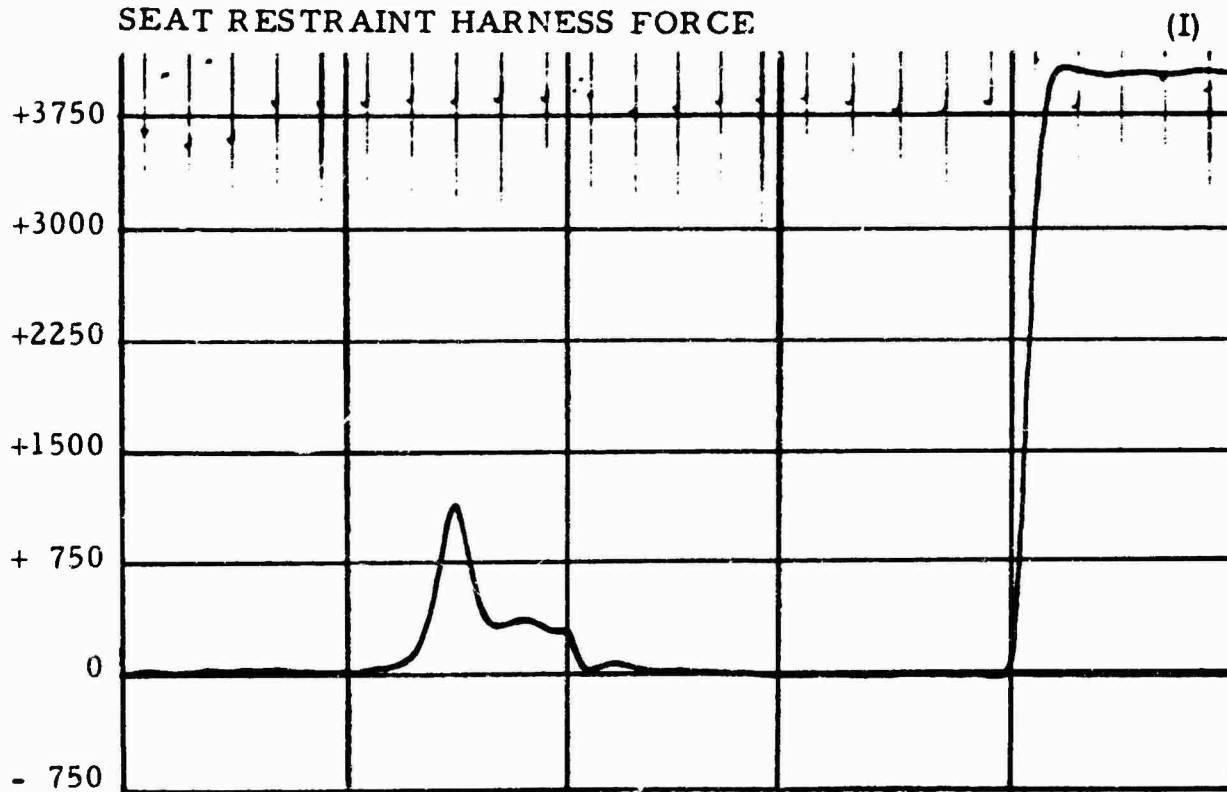## SLED LONGITUDINAL ACCELERATION   (J)

TIME (SECONDS)

Figure 43 (contd.). Data Time Histories - Vertol Seat - Test Condition No. 1.

Figure 44. Seat Belt Tiedown Failure - Vertol Seat -
Test Condition No. 2.

Figure 45. Posttest View of Vertol Seat - Test Condition No. 3.
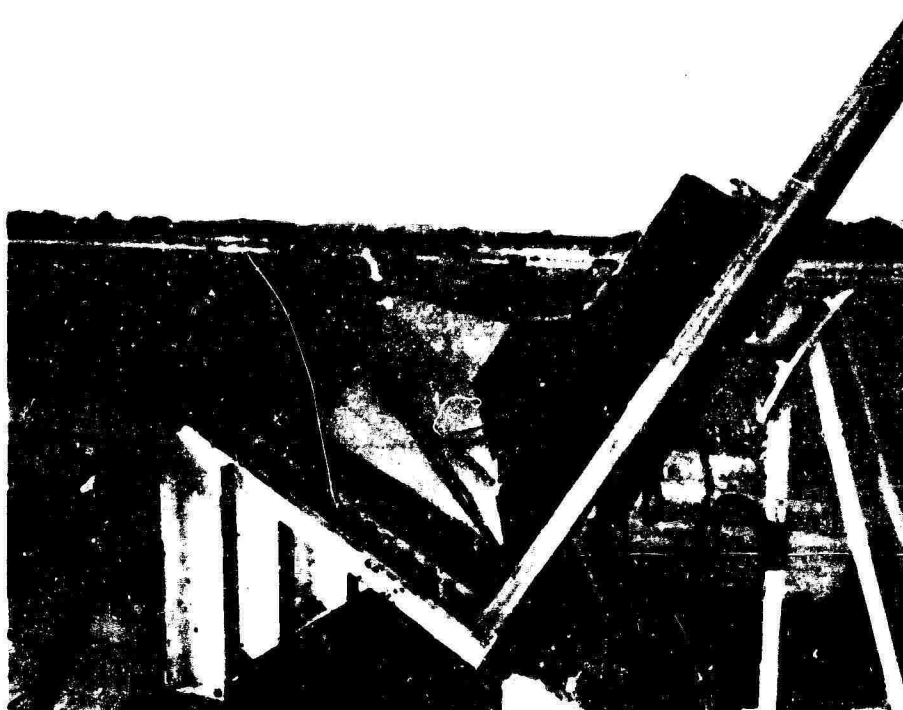
HALF LOAD LONGITUDINAL AND LATERAL TESTS
SEAT LATERAL ACCELERATION   (A)

SEAT LONGITUDINAL ACCELERATION   (B)

SEAT VERTICAL ACCELERATION   (C)

TIME (SECONDS)
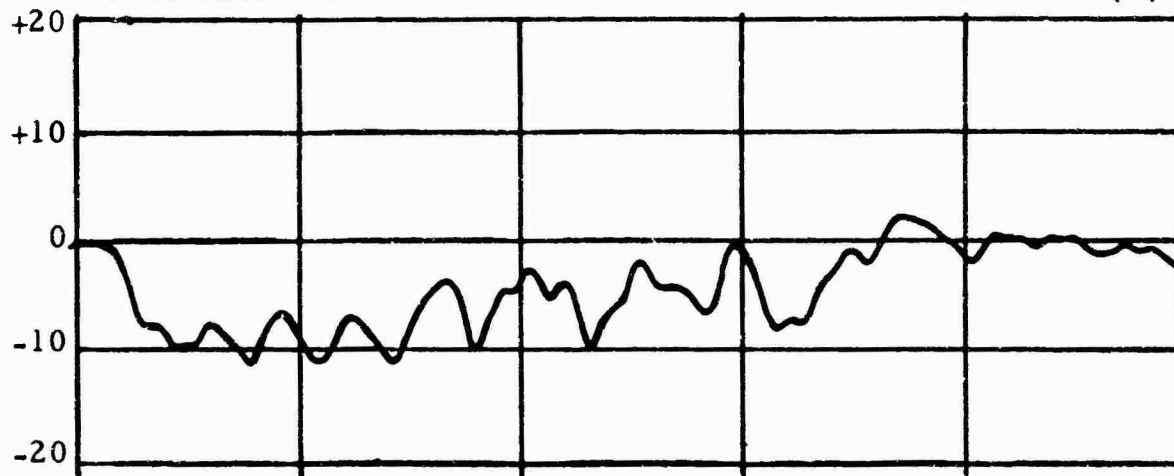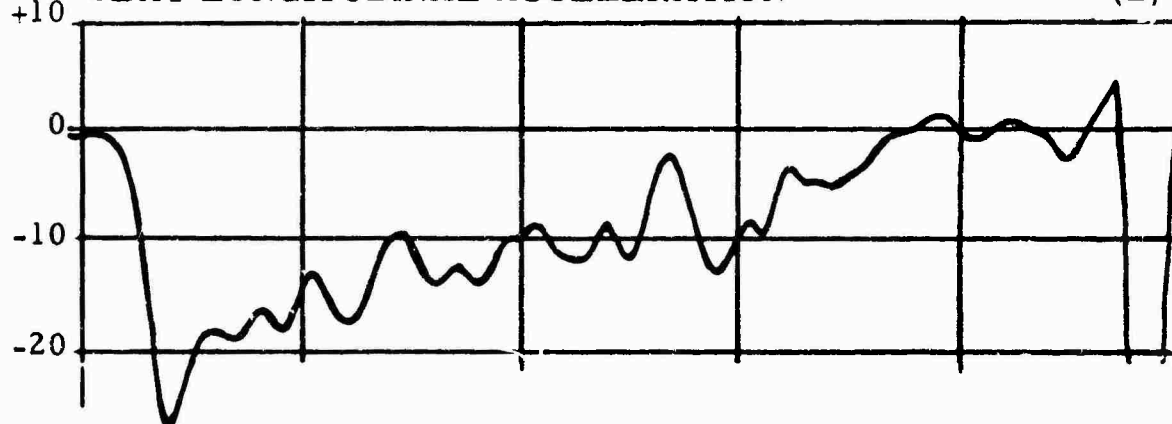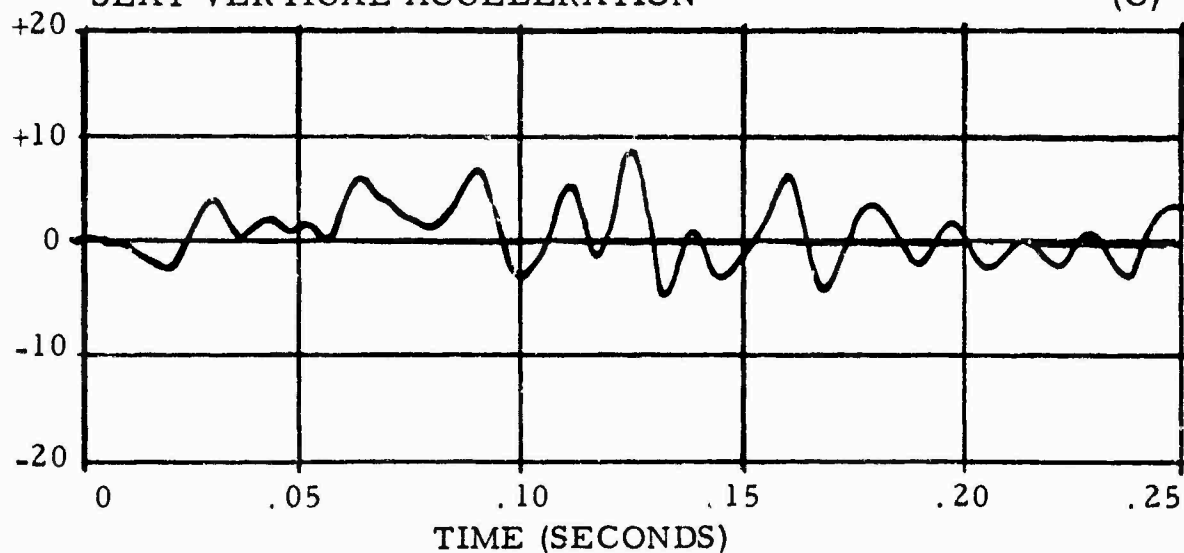
Figure 46. Data Time Histories - Vertol Seat -
Test Condition No. 2.

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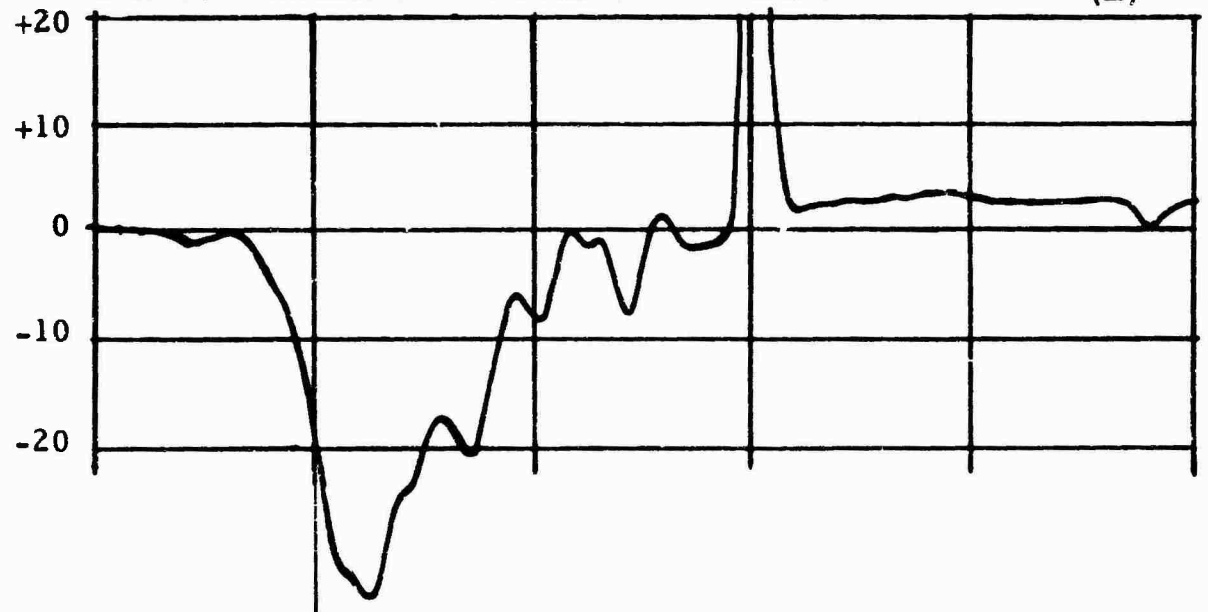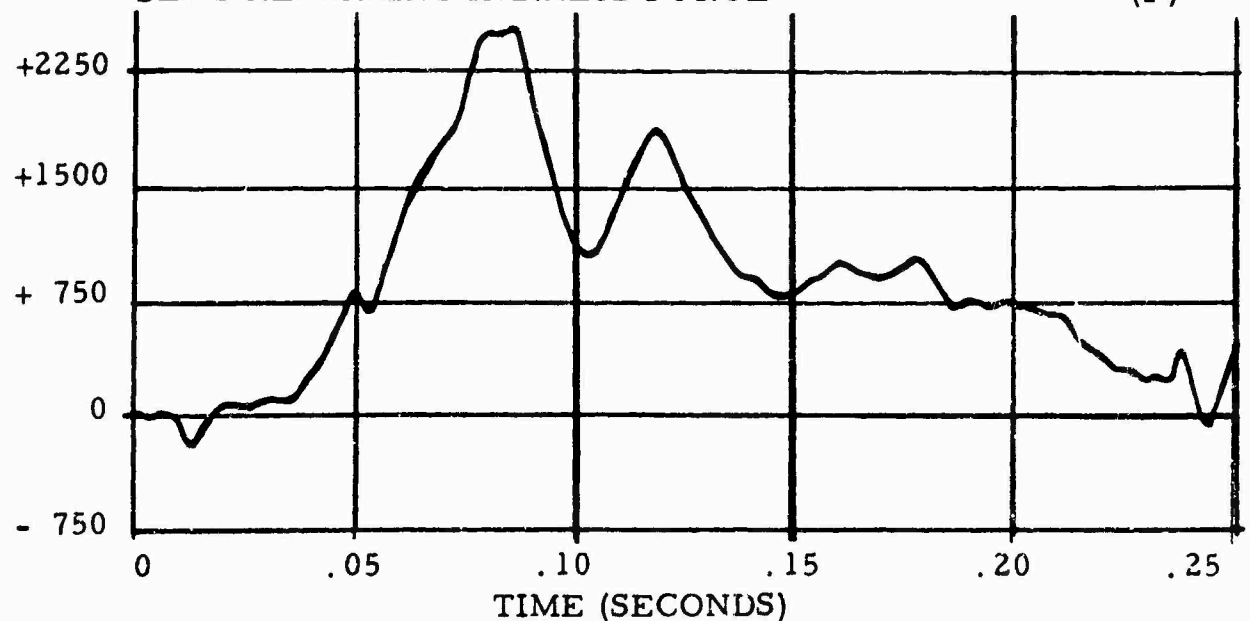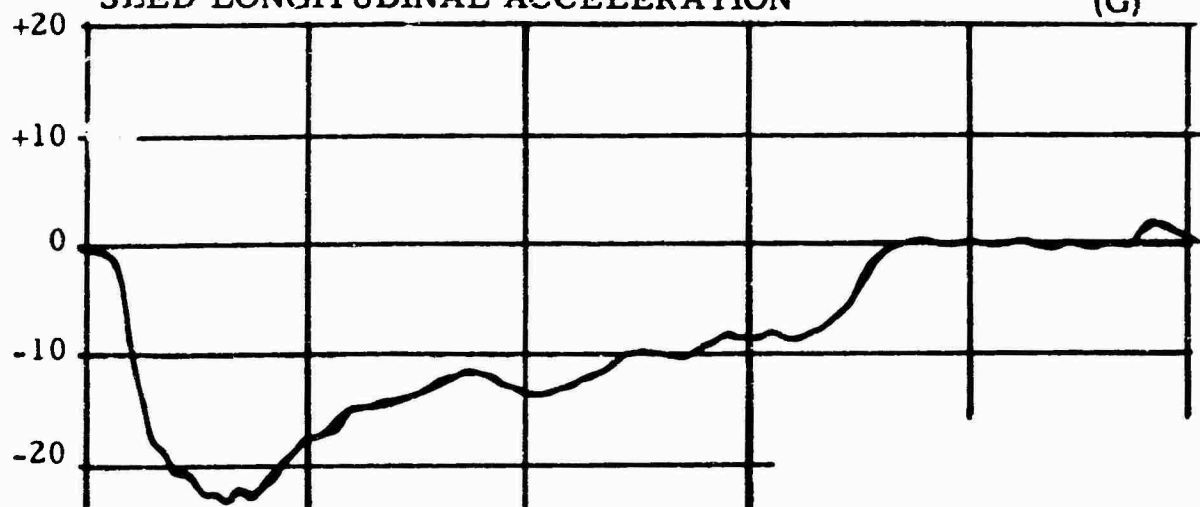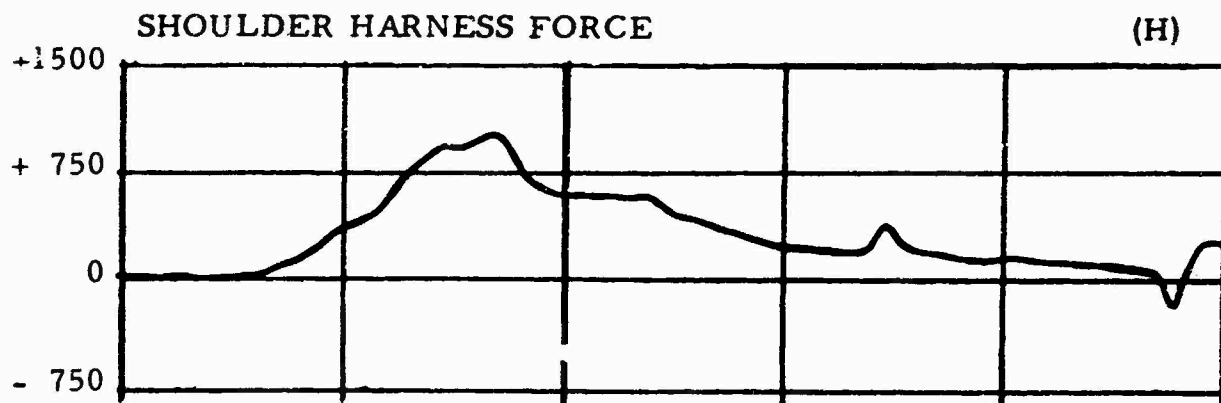Figure 46 (contd.). Data Time Histories - Vertol Seat -
Test Condition No. 2.

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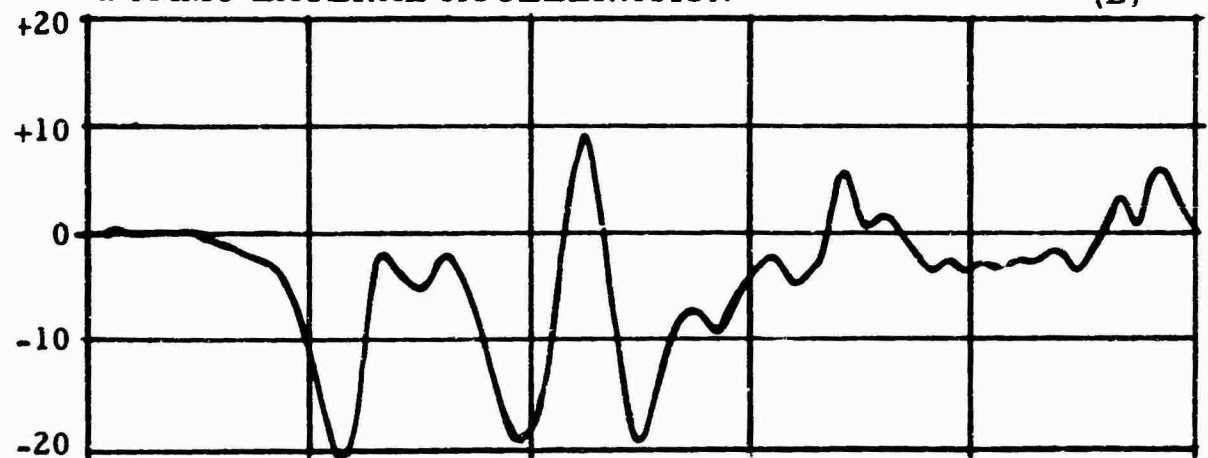
HALF LOAD LONGITUDINAL AND LATERAL TESTS
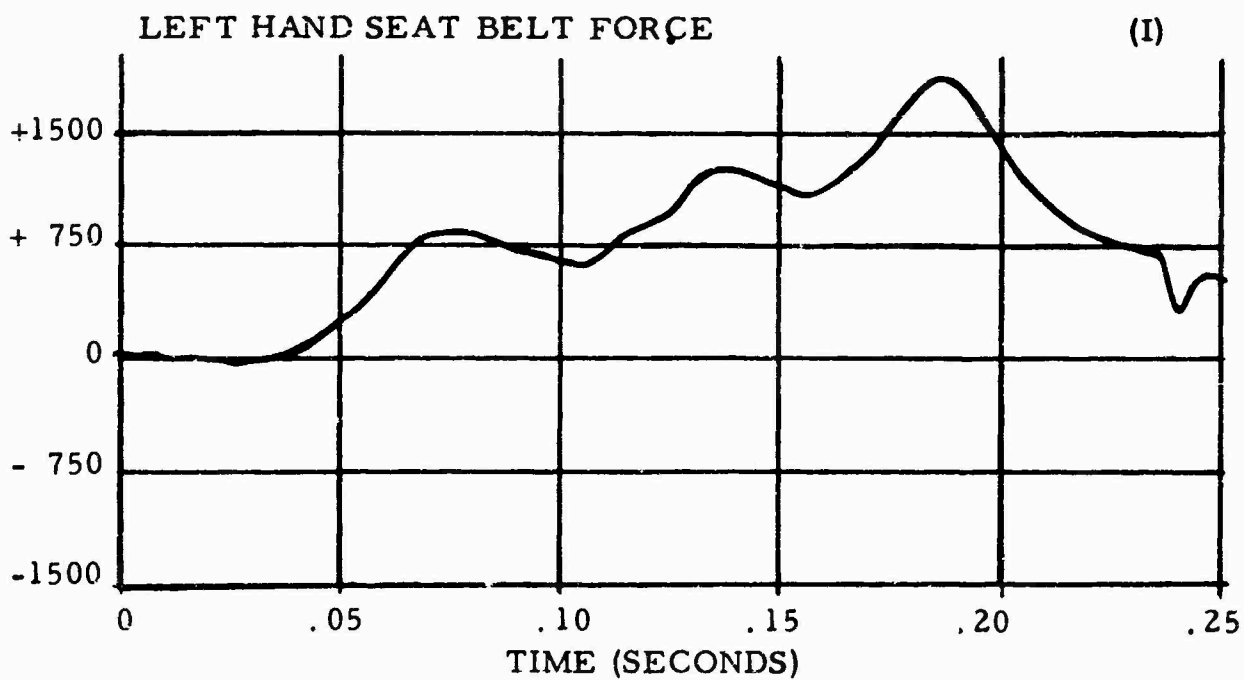
Figure 46 (contd.). Data Time Histories - Vertol Seat - Test Condition No. 2.

Figure 46E shows the dummy longitudinal response. This pulse is of lower amplitude, and the acceleration reduces to zero in about 60 percent of the normally expected time because of the rotation of the accelerometer "axis" with the dummy following the shoulder harness failure. The lateral response, Figure 46D, was also probably affected by the shoulder harness failure. The seat restraint harness load is shown in Figure 46F, and the seat belt load (left-hand side only) is given in Figure 46I. The seat belt itself did not fail.

VERTOL SEAT TEST CONDITION NO. 3

This was a full-load test with the seat mounted 28 degrees upward from the horizontal. The input pulse and cylinder pressure curves are shown in Figure 48G.

Recorded data on the seat and dummy would not be significant because the dummy restraint harness system failed almost immediately. The shoulder harness failed, as in the half-load tests, when the dummy stressed the chest armor. Both the seat belt fittings pulled out at the attachment fittings to the seat identically as shown in Figure 44. The dummy hit the safety cable with sufficient force to be severed and ejected from the seat and to fall to the ground a short distance from its original location. Sequence photographs are presented in Figure 47 and a posttest view of the seat is shown in Figure 45.

The energy absorbers were crushed at the forward part of the seat, as shown in Figure 45. This was caused more by the inertia of the dummy's leaving the seat than any attenuating action. The only other visible damage was the broken restraint harness.

t = 0.0 sec.; first motion

t = 0.035 sec.; sled movement, 1 ft.
(shoulder harness has failed)
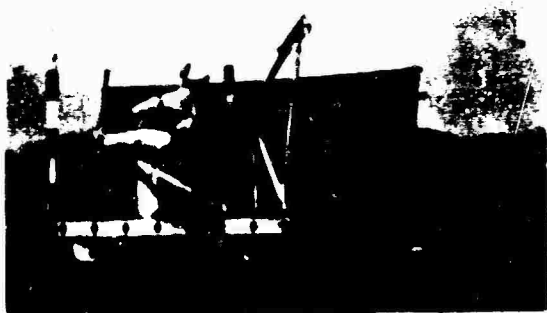
t = 0.053 sec.; sled movement, 2 ft.
(dummy is well out of seat)
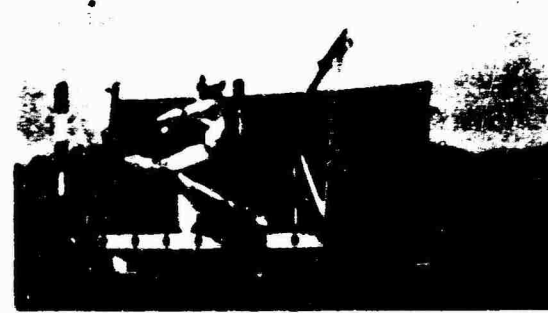
t = 0.066 sec.; sled movement, 3 ft.
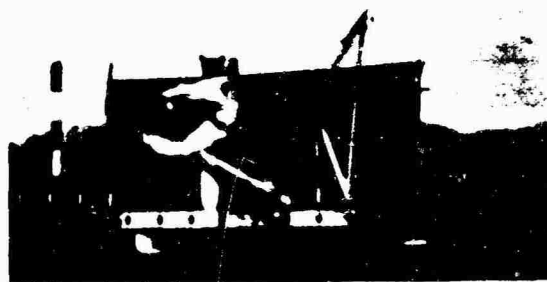
t = 0.076 sec.; sled movement, 4 ft.
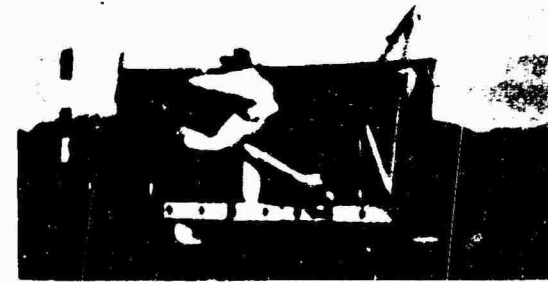
t = 0.086 sec.; sled movement, 5 ft.

Figure 47. Sequence Photographs of Vertol Seat - Test Condition No. 3.
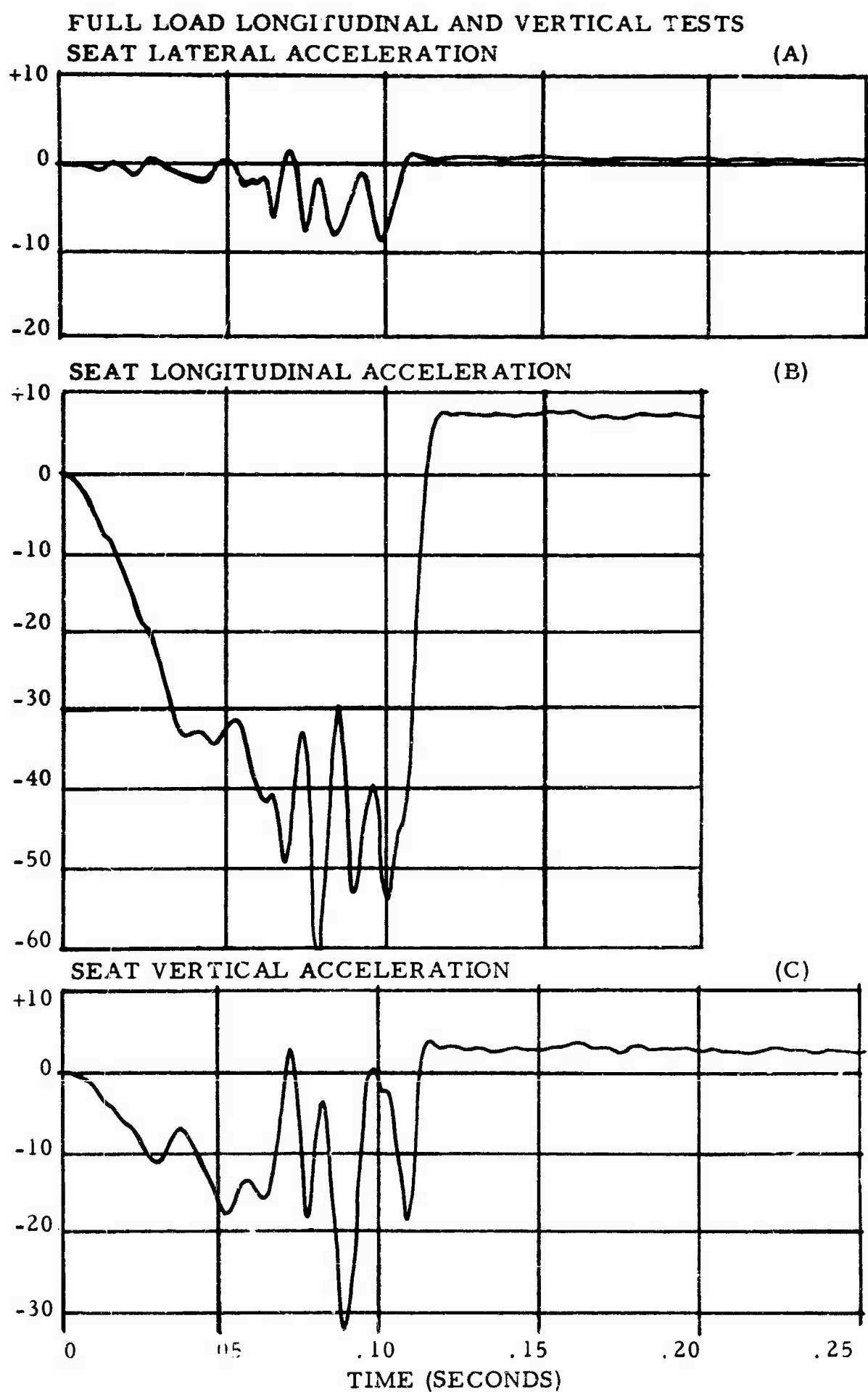
Figure 48. Data Time Histories - Vertol Seat -
Test Condition No. 3.
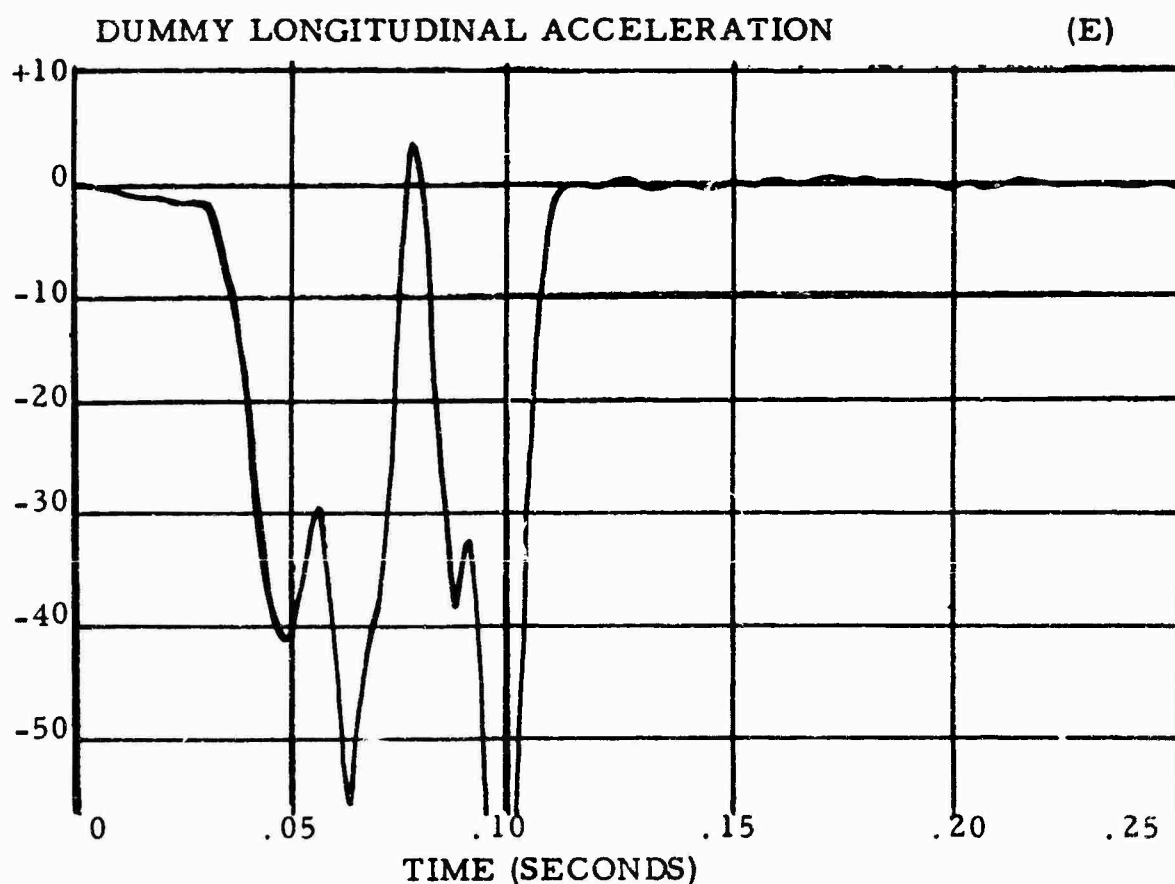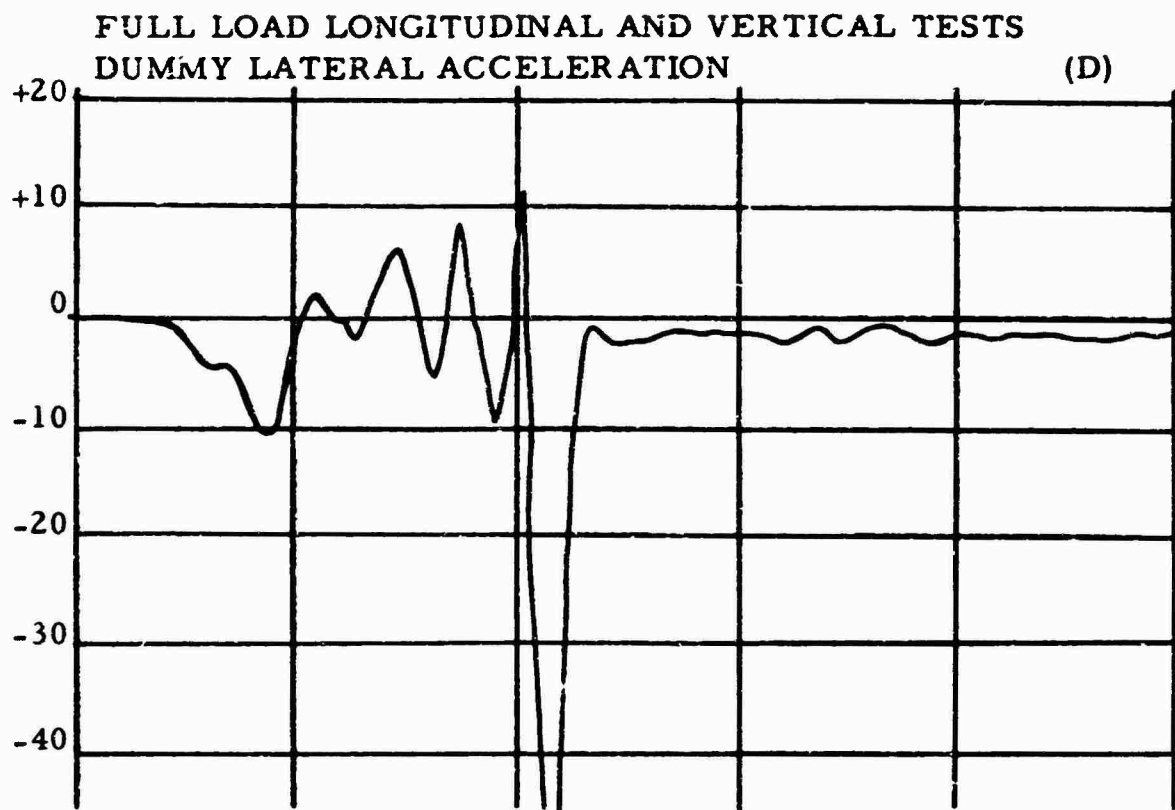
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FULL LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY LATERAL ACCELERATION   (D)

DUMMY LONGITUDINAL ACCELERATION   (E)

TIME (SECONDS)

Figure 48 (contd.). Data Time Histories - Vertol Seat -
Test Condition No. 3.

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FULL LOAD LONGITUDINAL AND VERTICAL TESTS
DUMMY VERTICAL ACCELERATION   (F)

SLED LONGITUDINAL ACCELERATION   (G)

TIME (SECONDS)

Figure 48 (contd.). Data Time Histories - Vertol Seat -
Test Condition No. 3.

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APPENDIX
TEST INSTRUMENTATION

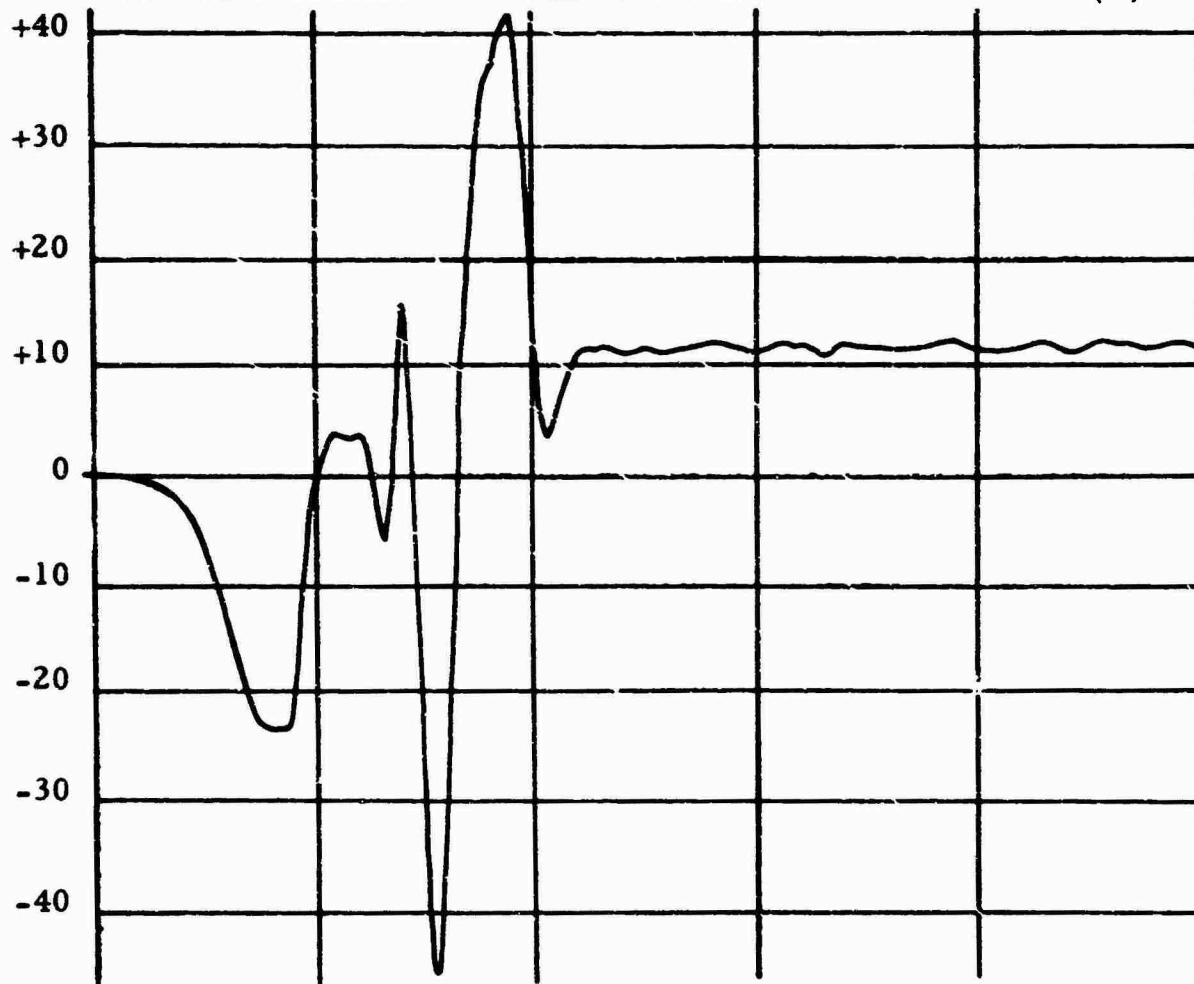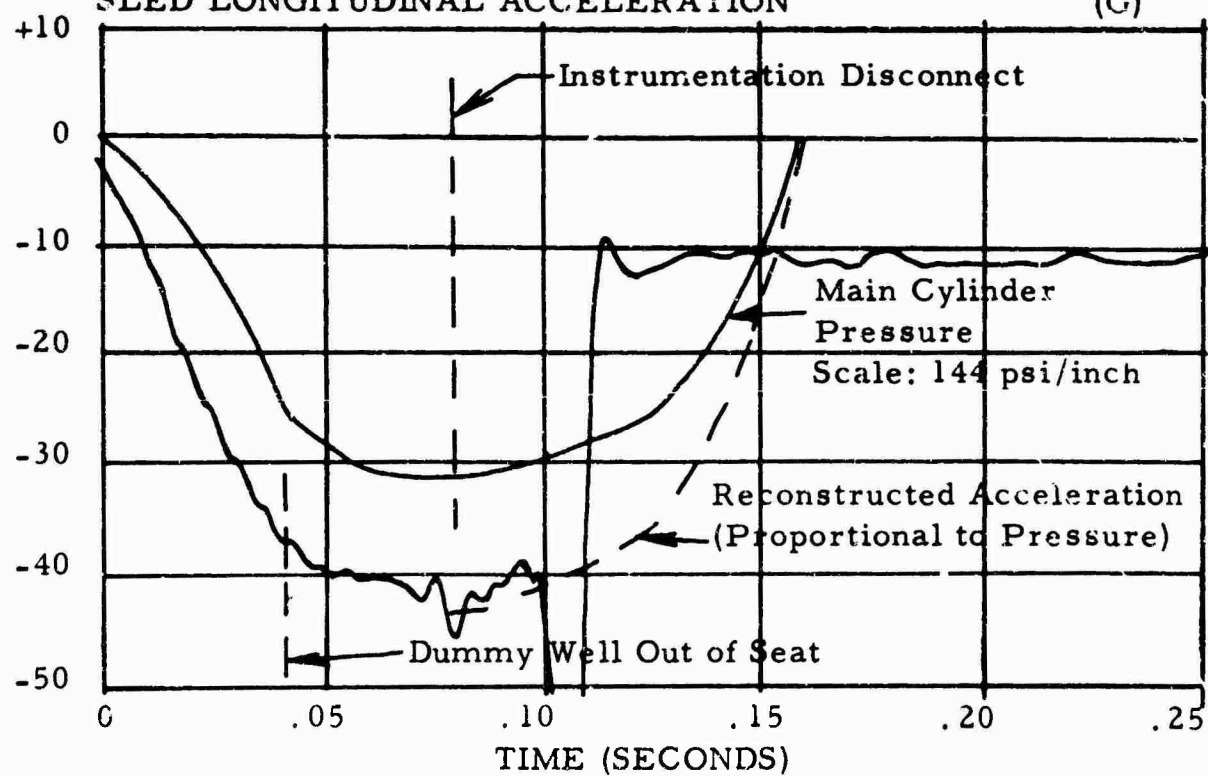| Item	Device	To Provide	Specifications
I	High Speed Motion Picture Camera	Time displacement of dummy and/or seat during acceleration pulse (see camera location, page 26)	a. Camera type - Photosonics Model 16B (16mm) b. Speed - 500 and 1000 frames per sec. c. Film capacity - 100 feet d. Film type - Ektachrome ER-430 high speed color
II	Normal Speed Motion Picture Camera	General photographic coverage (see camera location, page 26)	a. Camera type - Bolex Model 816 (16mm) b. Speed - 24 frames per sec. c. Film capacity - 100 feet d. Film type - Ektachrome ECO color film
III	Electrical Accelerometers	Sensing of acceleration in dummy on seats and on sled	a. Instrument type - Statham Model A5 and A6. Unbonded resistance strain gage bridge b. Ranges - 50 and 100G c. Approximate natural frequency - 575 cycles per second d. Accuracy - $\pm$ 1% of full-scale excursion e. Calibration procedure - <u>Initial calibration</u> - whirling arm accelerator <u>Pretest calibration</u> - output simulation by shunting precision resistor across one arm of strain gage bridge
IV	Load Tensiometer	Sensing of belt loads and seat leg loads	a. Instrument type - Calibrated strain bar AvSER design and fabrication b. Ranges - 0-4000 lbs. (seat belt load) 0-10000 lbs. (seat leg load) c. Accuracy - $\pm$ 2% of full-scale excursion d. Calibration procedure - <u>Initial calibration</u> - Dillon 10,000 lb. tensile test machine <u>Pretest calibration</u> - output simulation by shunting precision resistor across one arm of strain gage bridge
V	Velocity Sensor	Sensing of sled velocity at end of power stroke	This measurement was made by breaking two wires spaced two feet apart on end of sled by a vertical cutting bar installed on the track. The cutting of each wire provided an electrical step output which was recorded on the tape recorder. Time between breaks was determined from the tape recorder time base. Velocity was then calculated by following formula: $\text{velocity} = \dfrac{\text{displacement of sled (24)}}{\text{time between breaks}}$

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DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)	2a REPORT SECURITY CLASSIFICATION
Aviation Safety Engineering and Research 2641 E. Buckeye Road Phoenix, Arizona 85034	Unclassified
	2b GROUP

3 REPORT TITLE

SURVIVABILITY SEAT DESIGN DYNAMIC TEST PROGRAM

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final Technical Report

5 AUTHOR(S) *(Last name, first name, initial)*

Weinberg, L. W. T.
Turnbow, James W., Ph. D.

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
July 1965	113	

8a CONTRACT OR GRANT NO. DA 44-177-AMC-191(T) b PROJECT NO c Subtask 1P121401A1500301 d	9a ORIGINATOR'S REPORT NUMBER(S) USAAVLABS Technical Report 65-43 9b OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

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13 ABSTRACT This report presents the results of a series of dynamic tests conducted with four different concepts of experimental crew seats. The experimental seats were designed and constructed by four helicopter manufacturers. The seats were designed to withstand static load factors equivalent to those recommended in TRECOM Technical Report 63-4, "Crew Seat Design Criteria for Army Aircraft", dated February 1963. The design load factors recommended in the above referenced report were as follows: longitudinal-45G for 0.10 second; lateral-45G for 0.10 second; and vertical-25G for 0.10 second. Special kits for small arms ballistics protection were also designed and installed in the seats tested. These seats were designed exclusively using static load factors. No previous testing was conducted by any seat manufacturer prior to the conduct of these tests. The four seats were tested under four load conditions. Two of the conditions involved simultaneous half loads on the seats in two different seat positions, and two of the conditions involved full loads in two different seat positions. Only one of the four seats tested withstood the loads imposed for all four conditions. Three of the seats failed and were damaged beyond economical repair when each was subjected to the first full load test condition. This report also includes a detailed description of an acceleration device which was specially designed and fabricated for this series of tests.

DD FORM 1473 (1 JAN 64)

14. KEY WORDS	LINK A		LINK B		LINK C	
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Crash						
Survival						
Military Equipment						
Aircrew Seats						
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